I. C. S.
REFERENCE LIBRARY

SERIES TEXTBOOKS PREPARED FOR THE STUDENTS OF THE INTERNATIONAL CORRESPONDENCE SCHOOLS AND CONTAINING IN PERMANENT FORM THE INSTRUCTION PAPERS, EXAMINATION QUESTIONS, AND KEYS USED IN THEIR VARIOUS COURSES

THE TRANSITION SPIRAL
EARTHWORK
RAILROAD LOCATION
TRESTLES
TRACKWORK
RAILROAD BUILDINGS AND MISCELLANEOUS STRUCTURES
HIGHWAYS
PAVEMENTS
CITY SURVEYING
CITY STREETS
CONSTRUCTION DRAWING

SCRANTON
INTERNATIONAL TEXTBOOK COMPANY
133

PRESS OF
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.

29142

133

CONTENTS

E NSITION SPIRAL	*Section*	*Page*
u :levation of Outer Rail	53	1
)…itions Relating to Curves	53	3
ieneral Properties of the Transition Spira'		9
'angent Distances		22
'o Lay Out a Spiral in the Field		26
nserting Spirals in Old Track	53	33
·election of Spirals	53	37
'ables	53	45
HWORK		
:uts and Fills	54	1
'ield Work	54	5
:omputation of Volume	54	15
:orrection for Curvature: General Case	54	45
:orrection for Curvature: Side-Hill Work	54	51
hrinkage of Earthwork	54	55
ccuracy of Earthwork Computations	54	58
laulage	54	59
ost of Earthwork	54	71
·lasting	54	73
ROAD LOCATION		
heory	55	1
econnaissance	55	7
rairie Route	55	10
alley Route	55	12
ross-Country Route	55	13
lountain Route	55	15
reliminary Survey	55	18

RAILROAD LOCATION—*Continued*	*Section*	*Page*
Preliminary Estimate	55	36
Paper Location	55	43
Location Field Work	55	54
Final Location	55	57
Right of Way	55	60
Vertical Curves	[illegible]	61
TRESTLES		
Pile Bents	[illegible]	7
Framed Bents	[illegible]	12
Floor System	56	20
Bracing	56	28
D[illegible]	56	32
S[illegible]ns for Wooden Trestles	56	46
TRACKWORK		
Ballast	57	1
Ties	57	3
Rails	57	7
Rail Fastenings	57	13
Cost and Quantities of Materials	57	19
Laying the Ballast and Ties	57	24
Laying the Rails	57	28
Curved Track	57	34
Maintenance of Track	57	40
Turnouts	58	1
Switches	58	3
Frogs and Guard-Rails	58	11
Formulas and Calculations for Turnouts	58	19
Connecting Curves	58	35
Cross-Overs	58	44
Ladder Tracks	58	54
Laying Out Turnouts	58	55
Crossings	58	63
RAILROAD BUILDINGS AND MISCELLANEOUS STRUCTURES		
Stations	59	1
Section Buildings and Engine Houses	59	3

RAILROAD BUILDINGS AND MISCELLANEOUS STRUCTURES—*Continued*	*Section*	*Page*
Water Stations	59	11
Coaling Stations	59	19
Turntables	59	24
..nces	59	27
Freight Yards	59	33
Cattle Yards	59	39
Ash-P and Cars	59	43
IWAY		
Res..nce to Traction	60	3
Friction and Air Resistance	60	3
Resistance of Gravity	[illegible]	8
Tractive Power of Horses	[illegible]	12
Gradients	60	14
Form and Width of Roadbed	60	18
Reconnaissance and Preliminary Survey	60	21
Selection of Route	60	24
Comparison of Routes	60	27
Final Location	60	36
Staking Out the Work	60	39
Earthwork	60	41
Drainage	61	1
Construction of Drains	61	3
Natural Roads	61	9
Broken-Stone Roads	61	11
Other Artificial Roads	61	19
Maintenance of Roads	61	22
Specifications and Contracts	61	23
EMENTS		
Choice of Pavements	62	3
Economics of Pavements	62	8
Paving Materials	62	19
Stone and Wood	62	21
sphalt	62	22
rick	62	27
and and Concrete	62	28

PAVEMENTS—*Continued*	*Section*	*Page*
Stone Pavements	62	30
Wooden Pavements	62	36
Asphalt and Coal-Tar Pavements	62	42
Brick Pavements	62	52
CITY SURVEYING		
Linear Measurements	63	2
Angular Measurements	[illegible]	8
Precision	[illegible]	12
Lot Surveys	[illegible]	17
Subdivisional Surveys	[illegible]	26
Grading Surveys	63	37
Monuments	63	45
Bench Marks	63	49
Office Records	63	52
CITY STREETS		
Width and Cross-Section of Roadway	64	1
Crown	64	3
Gutters and Curbs	64	10
Footwalks and Street Lawns	64	17
Crossing Stones	64	28
Street Intersections	64	29
Grades	64	41
CONSTRUCTION DRAWING		
Plate, Title: Railroad Construction	65	2
Plate, Title: Streets and Pavements	65	14
Plate, Title: Dams and Pipes	65	18

THE TRANSITION SPIRAL

PRELIMINARIES

SUPERELEVATION OF OUTER RAIL

1. As explained in *Kinematics and Kinetics*, a train in moving in a circular track exerts a centrifugal force on the rails that is directly proportional to the square of the velocity and inversely proportional to the radius of the curve. As the radius of the curve is inversely proportional to the degree of curve, the centrifugal force is directly proportional to the degree of curve. In order to avoid all danger of derailment, as well as the wear of both rail and wheel caused by their mutual pressure, the outer rail of the curve is **superelevated**; that is, made higher than the inner in such manner that the centripetal force necessary for the circular motion of the train will be furnished by a component of the normal pressure of the rails, and that there will be, therefore, no lateral pressure between rails and wheels. The difference e between the elevation of the outer rail and that of the inner is called the **superelevation** of the outer rail; and, in order that the conditions specified may be fulfilled, the following equation must be approximately satisfied (see *Kinematics and Kinetics*):

$$e = \frac{G' v^2}{g R} \qquad (1)$$

in which e = superelevation, in feet;

G' = horizontal distance, in feet, between centers of heads of rails;

R = radius of curve, in feet;

v = velocity of train, in feet per second;
g = acceleration due to gravity = 32.16 feet per second.

The gauge on curves is a little greater than on level track; for a gauge of 4 feet $8\frac{1}{2}$ inches, G' is approximately 4.9 feet. If the degree of curve is denoted by D, we have, very nearly, $R = \frac{5{,}730}{D}$. If the velocity, in miles per hour, is denoted by V, then

$$v = \frac{5{,}280}{60 \times 60} V = \frac{22}{15} V$$

Substituting these values in formula **1**, and rearranging,

$$e = .000058\, D\, V^2 \qquad (2)$$

2. Table I, at the end of this Section, gives the values of e corresponding to all values of V and D that are likely to be required in practice. This table is computed from a more accurate formula than the one just given. The latter formula is sufficiently exact if no tables are at hand.

Table I contains the theoretically best superelevations computed to accommodate the fastest train that will pass over the line. In practice, these figures are often modified, especially if the track is used for both freight and passenger traffic. A superelevation of more than 8 inches is rarely allowed in this case, for this would endanger the slower-moving freight trains. For sharp curves, slow-down orders must be issued. Some railroads make use of special tables of superelevations based on the kind of traffic to be accommodated.

EXAMPLE.—To find the superelevation for a 6° circular curve, if the velocity of the fastest train that is to pass over the curve is 50 miles per hour.

SOLUTION.—In Table I, in the same horizontal line with 6°, and in the column headed 50, we find .844. The superelevation is, therefore, .844 ft. Ans.

EXAMPLES FOR PRACTICE

Find, by Table I, the superelevations for the following circular curves and maximum train speeds:

1. $D = 4°$; $V = 60$. Ans. .811 ft.
2. $D = 10°$; $V = 40$. Ans. .898 ft.
3. $D = 18°$; $V = 30$. Ans. .906 ft.
4. $D = 45°$; $V = 15$. Ans. .559 ft.

DEFINITIONS

3. Transition Curves.—From Arts. **1** and **2**, it is seen that the entire outer rail of a circular curve from the P. C. to the P. T. should be elevated above the inner rail. Theoretically, it should attain this superelevation exactly at the P. C., for as long as the train is on the tangent the two rails should be at the same level, while the instant it enters the curve it should find the outer rail elevated.

It is, of course, impossible to make a sudden change in the elevation of the outer rail exactly at the P. C. It is, therefore, customary to begin to raise the outer rail at a point on the tangent back of the P. C., and gradually to increase the elevation until, at some point on the curve, the outer rail reaches the proper superelevation.

The objections to this method are that the superelevation on the tangent is not theoretically needed, while the proper superelevation is not given to the outer rail throughout the curve. When the train enters a curved track constructed in this way, a disagreeable lurch is felt. Then, too, in passing from a tangent to a curve, the trucks must take a new position with reference to the car body, and the couplers must move through an angle. With long cars and sharp curves, these motions are made very suddenly.

4. In order to overcome the shock and disagreeable lurch of trains due to the sudden change of direction and to the sudden change in elevation of the outer rail, a curve, called a **transition curve,** is introduced, the purpose of which is to connect the tangent with a circular curve in such a manner that the change from one to the other will take place gradually.

5. Center of Curvature.—Let P, Fig. 1, be a point on any curved line APB. From P draw two chords PM and PN, and at the middle points of these chords erect the perpendiculars LO' and HO'. The point O' in which these two lines meet is equally distant from the points M, P, and N; therefore, with O' as a center and a radius $O'P$, a circular arc CPR may be drawn that will pass through M, P, and N.

If, now, the points M and N are moved continually nearer to P, it is found that, as the chords shorten, the intersection O' approaches a definite limiting position O; this point, which O' approaches the more closely the shorter the chords are drawn,

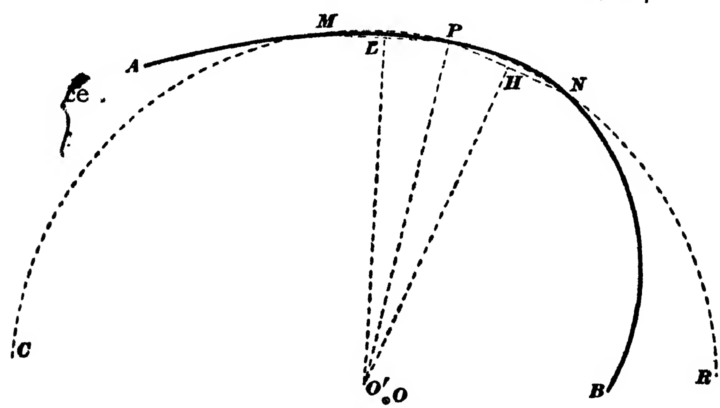


FIG. 1

is called the **center of curvature** of the curve AB at the point P. Its exact position is determined by the use of advanced mathematics; its approximate position may be found by drawing from P two very short chords, and finding the point of intersection of the perpendiculars at their middle points.

6. Osculating Circle and Radius of Curvature.—A circle drawn from O, Fig. 1, as a center, with OP as a radius, is called the **osculating circle** to the curve AB at the point P. This circle is tangent to the curve at P, and its radius OP is called the **radius of curvature** of the curve AB at the point P. The value of the radius of curvature at any

point of a curve can be determined by formulas given in works on the differential calculus.

Fig. 2 shows the osculating circles drawn at three points P_1, P_2, and P_3 of the curve CP_1P_2B. It should be noted that, as the curve becomes sharper, the radius of the osculating circle diminishes.

The **curvature**, or sharpness, of a curve is greater the smaller the radius of curvature. Thus, in Fig. 2, the curve CB

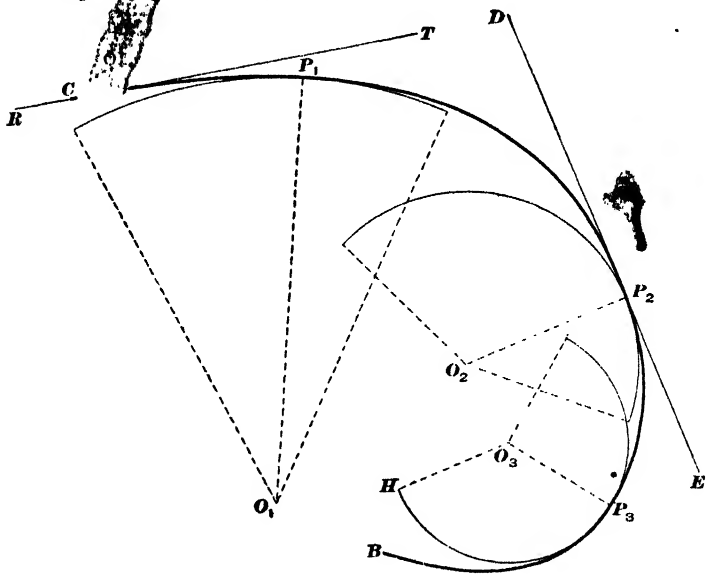


FIG. 2

has a greater curvature at P_3 than at P_2, and a greater curvature at P_2 than at P_1.

7. The **tangent** to any curve at any given point is the tangent to the osculating circle at that point. Thus, in Fig. 2, the tangent to the curve CB at P_2 is the line DE, tangent to the osculating circle O_2.

8. Degree of Curve.—The **degree of curve** *of a simple circular curve* is the angle between two radii drawn from the center to points on the curve 100 feet apart, the distance being measured on one or more chords. Thus,

if LM, Fig. 3, or $LM' + M'M$, Fig. 4, or $LM' + M'M'' + M''M''' + M'''M$, Fig. 5, is 100 feet, the degree of curve is the angle D.

In the best railroad practice, circular curves up to a 7° curve are measured with 100-foot chords, as shown in Fig. 3; from 7° to 14°, they are measured with 50-foot chords, as shown in Fig. 4; and from 14° upwards, they are measured with 25-foot chords, as shown in Fig. 5. Thus, an 8° curve is one in which two 50-foot chords together subtend an angle of 8° at the center; a 20° curve is a curve in which four 25-foot chords subtend an angle of 20° at the center. When the curve is measured in this way, the formula

$$R = \frac{5,730}{D}$$

will give the value of the radius with sufficient accuracy. It is evident that the greater the degree of curve, the greater is the curvature or sharpness of the curve.

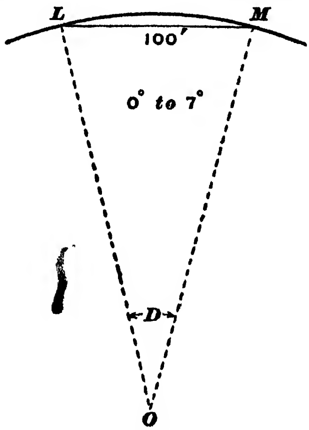


FIG. 3

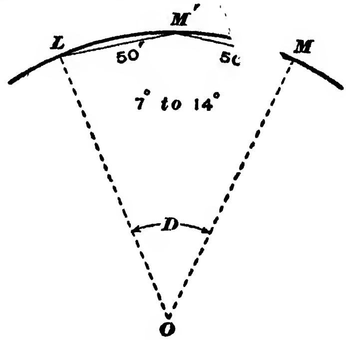


FIG. 4

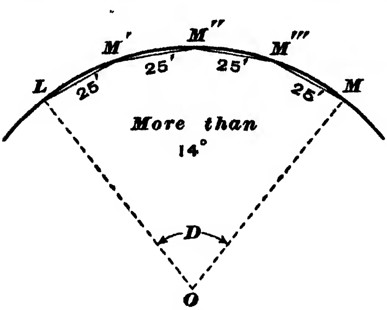


FIG. 5

9. The **degree of curve** *of any curve* at any given point is the degree of curve of a circular curve whose radius is equal to the radius of curvature, at the given point, of the

curve under consideration. Thus, the degree of curve of CB, Fig. 2, at P_1 is the degree of curve of a circular curve whose radius is $P_1 O_1$, the radius of curvature of the curve at P_1.

10. The curvature of a transition curve gradually increases from the P. C., where it is zero, to the point at which the transition and the circular curve meet, where it is equal to the curvature of the latter curve.

Thus, if CP_3, Fig. 2, is a transition curve connecting the tangent RT at C with a circular curve P_3H at P_3, the degree of curve of CP_3 gradually increases between C, where it is zero, and P_3, where it is equal to the degree of curve of the circular curve P_3H. The circular curve at P_3 is a part of the osculating circle to the transition curve at the same point.

11. The Transition Spiral.—The **transition spiral** is a transition curve in which the degree of curve at any point

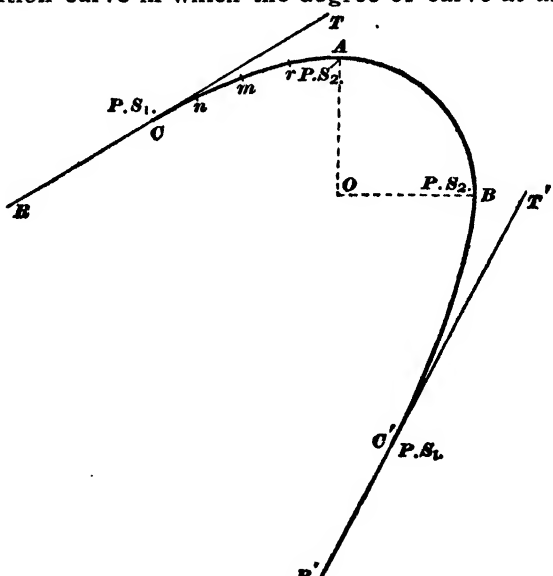


FIG. 6

increases directly as the distance of this point, measured along the curve, from the tangent. The degree of curve is always

zero at the tangent, and, at the point at which the spiral meets the circular curve, equals the degree of the circular curve.

The point at which the transition spiral joins the tangent is called the **point of spiral,** and is denoted by P. S_1 (see Fig. 6).

The point at which the transition spiral joins the circular curve is called the **second point of spiral,** and is denoted by P. S_2.

In Fig. 6, CA is a transition spiral connecting the tangent RT with the circular curve AB: C is the point of spiral P. S_1, and A is the second point of spiral P. S_2. If another spiral is inserted between the end B of the circular curve and the tangent $R'T'$, then, for this curve, B is the second point of spiral, and C' is the point of spiral.

The degree of curve of CA is zero at C, and at A it is equal to the degree of curve of AB. Between these points, it varies as the distance from C. For example, if AB is an 8° curve, the degree of curve of the spiral at a point m, half way between C and A, is $\frac{1}{2} \times 8° = 4°$; at n, one-fourth of the distance from C to A, it is $\frac{1}{4} \times 8° = 2°$; at a point r, three-fourths of the distance from C to A, it is $\frac{3}{4} \times 8° = 6°$.

As with simple circular curves, a distance of 100 feet on the spiral is called a **station.**

GENERAL PROPERTIES OF THE TRANSITION SPIRAL

12. Degree of Curve at Any Point on the Spiral. The **unit degree of curve of spiral** is the degree of curve of the spiral at a point 100 feet from the point of spiral. In Fig. 6, if Cn is 100 feet, the unit degree of curve of spiral is the degree of curve of the spiral at n. In the example given in Art. **11**, the unit degree is 2°.

Let a = unit degree of curve of spiral;
l = distance, in stations, from point of spiral to any other point of the curve;
d = degree of curve of spiral at this point.

From the definition of a transition spiral, it follows that

$$d = a\,l \qquad (1)$$

At the second point of spiral P. S.$_2$, the degree of curve of spiral equals the degree of curve D of the simple circular curve. If L is the whole length of the spiral, expressed in stations, formula **1** becomes

$$D = a\,L \qquad (2)$$

from which

$$a = \frac{D}{L} \qquad (3)$$

The last formula gives the unit degree of curve of spiral when the degree of the circular curve and the length of spiral are known.

EXAMPLE 1.—If CA, Fig. 6, is a transition spiral 400 feet long connecting the tangent with an 8° curve, and if n, m, and r are distant 1, 2, and 3 stations, respectively, from P. S.$_1$, find the degree of curve of spiral at n, m, r, and A, the unit degree of curve of spiral being 2°.

SOLUTION.—Applying formula **1**, we have:

$$\left.\begin{array}{lll} \text{At } n, & l = 1 \text{ sta.}; & d = 1 \times 2^\circ = 2^\circ \\ \text{At } m, & l = 2 \text{ sta.}; & d = 2 \times 2^\circ = 4^\circ \\ \text{At } r, & l = 3 \text{ sta.}; & d = 3 \times 2^\circ = 6^\circ \\ \text{At } A, & L = 4 \text{ sta.}; & D = 4 \times 2^\circ = 8^\circ \end{array}\right\} \text{Ans.}$$

EXAMPLE 2.—A spiral 360 feet long connects a tangent with a $4° 30'$ curve. What is the unit degree of curve of spiral?

SOLUTION.—Here, $D = 4° 30' = 4.5°$; $L = 3.6$ sta.; hence, by formula **3**,

$$a = 4.5° \div 3.6 = 1.25° = 1° 15'. \text{ Ans.}$$

EXAMPLES FOR PRACTICE

1. A spiral 240 feet long connects a tangent with a 3° circular curve. Find: (*a*) the unit degree of curve of spiral; (*b*) the degree of curve of spiral at points 50, 150, 200, and 240 feet from the P. S_1.

Ans. $\begin{cases} (a) & 1° 15' \\ (b) & 37.5', 1° 52.5', 2° 30', \text{ and } 3° \end{cases}$

2. In the following two examples, find *a* for each spiral, and also the values of *d* at the points indicated: (*a*) Spiral 600 feet long connecting with a 2° curve; points 100, 200, 300, 400, 500, and 600 feet from P. S_1. (*b*) Spiral 150 feet long connecting with a 6° curve; points 20, 30, 60, and 150 feet from P. S_1.

Ans. $\begin{cases} (a) & a = 20'; d = 20', 40', 1°, 1° 20', 1° 40', \text{ and } 2° \\ (b) & a = 4°; d = 48', 1° 12', 2° 24', \text{ and } 6° \end{cases}$

---

13. Superelevation of Outer Rail at Any Point of the Spiral.—The superelevation at any point of the spiral should equal the superelevation required by the osculating circle at that point. The degree of curve of the osculating circle, which is the same thing as the degree of curve of spiral at the point, may be computed by formula **1**, Art. **12**, and the corresponding superelevation computed by the formula in Art. **1**, or taken from Table I at the end of this Section. Another method, which is usually simpler, is as follows: If e is the superelevation at the P. S_2, and D is the degree of the circular curve, we have (Art. **1**),

$$e = .000058\, D V^2$$

Writing $a L$ for D (Art. **12**),

$$e = .000058\, a L V^2 \qquad (1)$$

Similarly, if e_l is the superelevation at any point whose distance from P. S_1 is l stations,

$$e_l = .000058\, a l V^2 \qquad (2)$$

Therefore, dividing (2) by (1), $\frac{e_l}{e} = \frac{l}{L}$

and
$$e_l = e \times \frac{l}{L}$$

By this formula, e_l can be computed for any point on the spiral, when e has been computed or taken from the table.

EXAMPLE.—A spiral 400 feet long connects with a 6° curve. To find the superelevation at points 50 feet apart on the spiral, if a train speed of 50 miles per hour is to be allowed for.

SOLUTION BY TABLE.—The unit degree of curve of spiral is first found. Here, $D = 6°$, and $L = 4$ sta.; therefore, by formula **3**, Art. **12**,

$$a = 6° \div 4 = 1° 30'$$

Next, the degree of curve of spiral at each point is found by formula **1**, Art. **12**:

At first point, $l = \frac{1}{2}$; $d = 1° 30' \times \frac{1}{2} = 0° 45'$
At second point, $l = 1$; $d = 1° 30' \times 1 = 1° 30'$
At third point, $l = \frac{3}{2}$; $d = 1° 30' \times \frac{3}{2} = 2° 15'$
At fourth point, $l = 2$; $d = 1° 30' \times 2 = 3° 0'$
At fifth point, $l = \frac{5}{2}$; $d = 1° 30' \times \frac{5}{2} = 3° 45'$
At sixth point, $l = 3$; $d = 1° 30' \times 3 = 4° 30'$
At seventh point, $l = \frac{7}{2}$; $d = 1° 30' \times \frac{7}{2} = 5° 15'$
At P. S_2, $l = 4$; $d = 1° 30' \times 4 = 6° 0'$

From Table I, the following superelevations are obtained, using interpolation when necessary:

$$\left.\begin{array}{lll}
\text{At first point,} & \frac{45}{60} \times .143 \ldots\ldots\ldots & = .107 \text{ ft.} \\
\text{At second point,} & \ldots\ldots\ldots\ldots\ldots & = .214 \text{ ft.} \\
\text{At third point,} & .285 + \frac{1}{4} \times (.427 - .285) & = .321 \text{ ft.} \\
\text{At fourth point,} & \ldots\ldots\ldots\ldots\ldots & = .427 \text{ ft.} \\
\text{At fifth point,} & .427 + \frac{3}{4} \times (.568 - .427) & = .533 \text{ ft.} \\
\text{At sixth point,} & .568 + \frac{1}{2} \times (.707 - .568) & = .638 \text{ ft.} \\
\text{At seventh point,} & .707 + \frac{1}{4} \times (.844 - .707) & = .741 \text{ ft.} \\
\text{At P. S}_2 & \ldots\ldots\ldots\ldots\ldots & = .844 \text{ ft.}
\end{array}\right\} \text{Ans.}$$

SOLUTION BY FORMULA.—From Table I, the value of e at P. S_2 is found to be .844 ft. The superelevation at the other points is found by the formula $e_l = e \times \frac{l}{L}$. At P. S_1, $e_l = 0$.

$$\left.\begin{array}{ll}
\text{At first point,} & e_l = .844 \times \frac{1}{8} = .106 \text{ ft.} \\
\text{At second point,} & e_l = .844 \times \frac{1}{4} = .211 \text{ ft.} \\
\text{At third point,} & e_l = .844 \times \frac{3}{8} = .317 \text{ ft.} \\
\text{At fourth point,} & e_l = .844 \times \frac{1}{2} = .422 \text{ ft.} \\
\text{At fifth point,} & e_l = .844 \times \frac{5}{8} = .528 \text{ ft.} \\
\text{At sixth point,} & e_l = .844 \times \frac{3}{4} = .633 \text{ ft.} \\
\text{At seventh point,} & e_l = .844 \times \frac{7}{8} = .739 \text{ ft.}
\end{array}\right\} \text{Ans.}$$

The results differ slightly from those of the first solution, because the formula given in Art. 1 is only approximate. The differences, however, are unappreciable in practical work.

EXAMPLES FOR PRACTICE

Find by Table I the superelevation at each station of the following three spirals:

1. Length = 400 feet; degree of circular curve = 2°; greatest train velocity = 60 miles per hour.

Ans. $\begin{cases}\text{At P. S}_1\text{, 0; at Sta. 1, .103; at Sta. 2, .206;}\\ \text{at Sta. 3, .308; at P. S}_2\text{, .41 ft.}\end{cases}$

2. Length = 500 feet; D = 10°; greatest train velocity = 40 miles per hour. Ans. .000, .183, .365, .545, .723, and .898 ft.

3. Length = 240 feet; D = 6°; greatest train velocity = 60 miles per hour. Ans. .000, .511, 1.006, and 1.196 ft.

---

14. Advantages of the Transition Spiral.—The student is now prepared to understand the advantages gained by the use of the transition spiral. On leaving the tangent *R C*, Fig. 6, the train passes over a curve whose curvature continually becomes sharper and sharper until finally it becomes equal to that of the circular curve *A B*. At each point of the track *C A*, the superelevation is exactly what it should be to correspond to the curvature, and besides this the direction of motion is changed gradually and uniformly from the direction on the tangent to that on the curve *A B*. This insures smooth riding and greatly lessens lurching and jarring, which are so injurious to the roadbed and rolling stock. While it is true that the superelevation must be computed for the maximum train speed, yet transition spirals are advantageous for low speeds also.

15. Although a great number of American roads employ transition curves, there are still many lines on which they have not come into use. It may, therefore, not be out of place to state one or two instances in which their value has been clearly shown.

There is a curve on the Lehigh Valley Railroad over which the Black Diamond Express now runs sometimes as

fast as 75 miles per hour. The curve is a 4° curve, 1,000 feet long, at which for many years all trains were obliged to slow down. It was seriously contemplated to change the line to lighter curvature at a cost of about $1,500. Instead of this, a spiral 240 feet long was inserted, when for the first time in 25 years a slow-down was not required for this curve.

An exactly similar result was attained on the Cleveland, Cincinnati, Chicago & St. Louis Railroad by spiraling the numerous curves near Sydney, Ohio. These were on a down grade and the trains were obliged to reduce speed greatly before the spirals were inserted; afterwards, the speed was not reduced.

The cost of spiraling curves on new track is scarcely appreciable, the only expense being the slight additional time required from the engineer. When properly chosen spirals are inserted in old track, the rails need to be thrown but little, if any, more than would be necessary in realinement without spirals. It has even been the experience in some divisions that the cost of maintenance of track was actually less during the years in which the curves were being spiraled than in the years preceding.

16. Angle of Deviation and Angle of Deflection. Let CA, Fig. 7, be a spiral connecting the tangent RT with the circular curve AB. Let P be any point on the spiral and HN a tangent to the spiral at the point P.

The angle that a tangent drawn to the spiral at any point P forms with the original tangent RT is called the **deviation angle** for the point P. It is represented by the Greek small letter δ (called *delta*).

In the figure, the angle HNT is the deviation angle for the point P.

If l is the distance CP expressed in stations, and a is the unit degree of curve of spiral, then

$$\delta = \tfrac{1}{2} a l^2 \qquad (1)$$

This and other formulas relating to the spiral are here given without deriving them, as their derivation requires the use of advanced mathematics.

When the point P coincides with the P. S.₂, the deviation angle becomes LKT, which is represented by the Greek capital letter Δ (called *delta*). If L is the whole length CA of the spiral, formula **1** becomes, for the P. S.₂,

$$\Delta = \tfrac{1}{2} a L^2 \qquad (2)$$

Since $LKT = AEC$, it follows that Δ is the whole **central angle** of the spiral, which measures the whole change

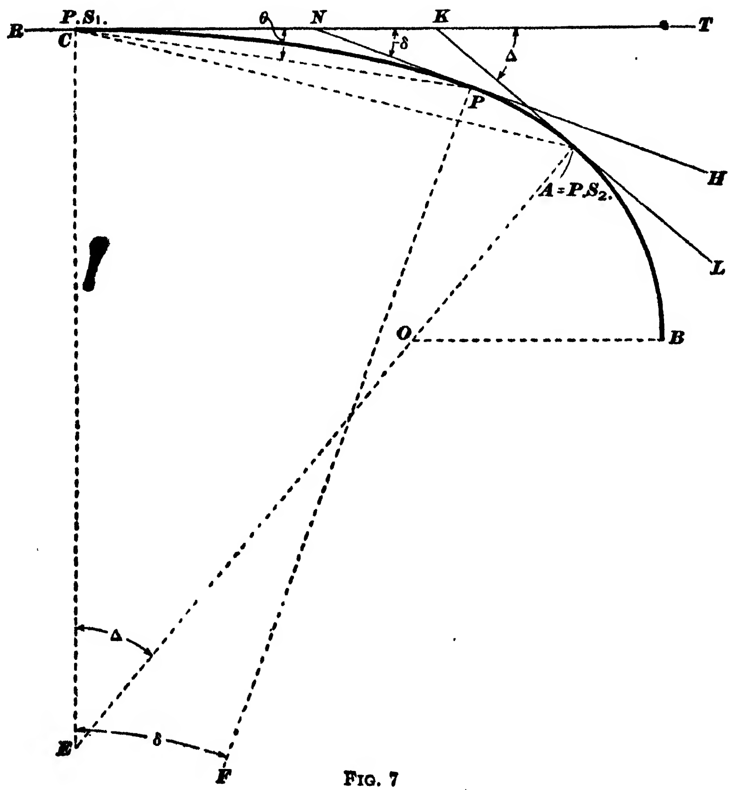


FIG. 7

in direction of the track between the original tangent and the P. S.₂.

17. The angle between the original tangent and a chord drawn from the P. S.₁ to any point of the spiral is called the **deflection angle** to this point. It is represented by the Greek letter θ (called *theta*). In Fig. 7, TCP is the

deflection angle for the point P. It is the angle that must be deflected at the P. S_1 from the original tangent, in order to locate the point P of the spiral.

It can be shown that θ is slightly less than $\frac{1}{3}\delta$. The formula connecting θ and δ is

$$\theta = \tfrac{1}{3}\delta - N$$

in which the value of N may be taken from the accompanying small table. Intermediate values may be found by interpolation.

$\frac{1}{3}\delta$ Degrees	N Minutes	$\frac{1}{3}\delta$ Degrees	N Minutes
3	.0	8	.7
4	.1	9	1.0
5	.2	10	1.4
6	.3	11	1.9
7	.5	12	2.4

EXAMPLE.—A spiral 600 feet long connects a tangent with a 12° curve. To find the deviation and deflection angles for a point 580 feet from the P. S_1.

SOLUTION.—By formula **3**, Art. **12**, the unit degree of curve of spiral is $12° \div 6 = 2°$. Since the point is 5.8 sta. from the P. S_1, $l = 5.8$. Therefore, by formula **1**, Art. **16**,

$$\delta = \tfrac{1}{2} \times 2° \times 5.8^2 = 33.64° = 33° \, 38.4'. \text{ Ans.}$$

To find the deflection angle, we have,

$$\tfrac{1}{3}\delta = 11° \, 12.8'$$

Interpolating from the table just given,

$$N = 1.9' + \tfrac{12}{60} \times (2.4' - 1.9') = 2.0'$$

Therefore, $\theta = \frac{1}{3}\delta - N = 11° \, 10.8'$ Ans.

18. Tables of Transition Spirals.—For laying out a spiral in the field, certain angles and distances are required. These may be computed from equations as they are needed, or their values may be computed for points on the spiral 10, 20, 30, etc. feet from the P. S_2, and these values tabulated. At the end of this Section, such tables are given, computed for fourteen different spirals. The unit degree of curve in Table II is small, and the spiral turns off very slowly from the tangent; in each table, the unit degree is larger than in the preceding; the spiral of Table XV turns off very rapidly from the tangent.*

*Eleven of these tables are taken by permission from an excellent treatise by Arthur N. Talbot, C. E., entitled "The Railway Transition Spiral." The others have been calculated for this work.

The use of these tables saves a great deal of labor. Sometimes, however, a spiral must be inserted for which no table is at hand, and then the various angles and distances must be computed by such formulas as have been given in the foregoing pages. If an engineer often has to use spirals for which he has no tables, he should compute the tables himself; by so doing he will save considerable time and expense, and otherwise expedite the work.

In the tables here given, the values of δ and θ are tabulated for fourteen different spirals. Above the first column of each table, there is given the value a of the unit degree of curve of spiral for which the table is computed. The first column, headed l, contains the lengths, in feet, of the various arcs CP, Fig. 7, between the P. S_1 and the corresponding points on the spiral. The second column, headed d, gives the degrees of curve of spiral at these points; the third column gives the corresponding deviation angle δ, and the fourth column the deflection angle θ.

EXAMPLE 1.—A spiral 200 feet long connects a tangent with a 5° circular curve. To find the degree of curve, the deviation angle, and the deflection angle to points 40 feet apart on the spiral.

SOLUTION.—By formula **3**, Art. **12**, $a = \frac{D}{L} = \frac{5°}{2} = 2° 30'$. This corresponds to Table XII.

For the first point, 40 feet from P. S_1, we find, in the same horizontal line with 40, $d = 1°$, $\delta = 12'$, and $\theta = 4'$. For the second point, we look in the table opposite 80 in the first column, and similarly with the others. The results are as follows:

DISTANCE (FEET) OF POINT FROM P. S_1	DEGREE OF CURVE OF SPIRAL	DEVIATION ANGLE	DEFLECTION ANGLE
40	1° 0′	0° 12′	0° 4′
80	2° 0′	0° 48′	0° 16′
120	3° 0′	1° 48′	0° 36′
160	4° 0′	3° 12′	1° 4′
200	5° 0′	5° 0′	1° 40′

EXAMPLE 2.—The station number of the P. S_1 is 68 + 25. The unit degree of curve of spiral is 1° 40′, and the length of spiral is 400 feet. To find the deflection angles to even stations of the spiral.

SOLUTION.—Since $a = 1° 40'$, Table X should be used. Sta. 69 is 75 ft. from the P. S_1; therefore, the deflection angle to Sta. 69 = 8′

$+\frac{5}{10}\times(10.5'-8')=9.2'$. The rest of the computation is as follows:

STATION	l, IN FEET		
69	75	$\theta = 8' + \frac{5}{10}\times(10.5' - 8') = 9.2'$	Ans.
70	175	$\theta = 48' + \frac{5}{10}\times(54' - 48') = 51.0'$	Ans.
71	275	$\theta = 2^\circ\ 1.5' + \frac{5}{10}\times(2^\circ\ 10.5' - 2^\circ\ 1.5') = 2^\circ\ 6.0'$	Ans.
72	375	$\theta = 3^\circ\ 48' + \frac{5}{10}\times(4^\circ\ .5' - 3^\circ\ 48') = 3^\circ\ 54.2'$	Ans.
P. S_2	400	$\theta = 4^\circ\ 26.5'$	Ans.

EXAMPLES FOR PRACTICE

1. In the following two examples, find the degree of curve of spiral, the deviation angle, and the deflection angle to points on the spiral 30, 60, 90, etc. feet from the P. S_1, and also the values of these angles at the P. S_2: (*a*) Spiral 200 feet long; degree of circular curve = 4°. (*b*) Spiral 160 feet long; degree of circular curve = 2°.

Ans. (*a*) Degrees of curve: 36′, 1° 12′, 1° 48′, 2° 24′, 3°, 3° 36′, and 4°; deviation angles: 5.5′, 21.5′, 48.5′, 26.5′, 2° 15′, 3° 14.5′, and 4°; deflection angles: 2′, 7′, 16′, 29′, 45′, 1° 5′, and 1° 20′
(*b*) Degrees of curve: 22.5′, 45′, 1° 7.5′, 1° 30′, 1° 52.5′, and 2°; deviation angles: 3.5′, 13.5′, 30.5′, 54′, 1° 24.5′, and 1° 36′; deflection angles: 1′, 4.5′, 10′, 18′, 28′, and 32′

2. If the station number of the P. S_1 is 116 + 38, the length of spiral 200 feet, and the unit degree of curve of spiral 3° 20′, find the degree of curve of spiral at each station and at the P. S_2.

Ans. 2° 4′, 5° 24′, and 6° 40′

3. In example 2, find the deflection angles to each station and to the P. S_2. Ans. 0° 12.8′, 1° 27.2′, and 2° 13′

19. Angle Between Chord and Tangent.—In Fig. 7, the exterior angle KNP of the triangle NPC is equal to the sum of the two opposite interior angles; that is,

$$TNP = NCP + CPN$$

or,

$$\delta = \theta + CPN$$

Therefore,

$$CPN = \delta - \theta$$

When running in a spiral, if the transit is moved forwards to some point P, and a backsight taken on P. S_1, then CPN is the angle that must be deflected from this direction to bring the telescope tanget to the spiral at P.

EXAMPLE.—A spiral 300 feet long connects with a 15° curve. When the stake at P. S_2 had been set, the transit was moved forwards to this point, and a backsight taken on P. S_1. Required, the angle that

must be deflected from this direction to bring the telescope tangent to the spiral and circular curve at P. S_2.

SOLUTION.—Here, $a = 15° \div 3 = 5°$ (Art. **12**); therefore, Table XIV must be used. The transit point is 300 ft. from the P. S_1; in the table, opposite 300, we find $\delta = 22° 30'$, and $\theta = 7° 29'$. By the formula in this article, the required angle is $22° 30' - 7° 29' = 15° 1'$. Ans.

20. Coordinates of the Spiral.—Let P, Fig. 8, be any point of a spiral, and PR the perpendicular distance from

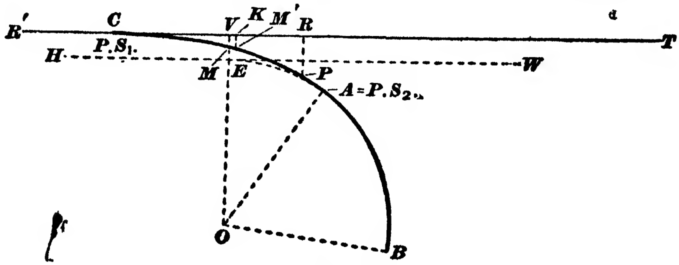


FIG. 8

this point to the original tangent. This perpendicular is represented by y, and its value in feet is given by the formula

$$y = PR = .291\, a\, l^3 - a^3 M \qquad (1)$$

in which a = unit degree of curve of spiral;

l = distance CP from P. S_1 to P, expressed in stations.

The value of M corresponding to any value of l may be taken from the accompanying table:

l	M	l	M	l	M
3.0	.003	5.5	.241	8.0	3.314
3.5	.010	6.0	.442	8.5	5.065
4.0	.026	6.5	.775	9.0	7.557
4.5	.059	7.0	1.301	9.5	11.033
5.0	.124	7.5	2.109	10.0	15.800

The distance CR, measured along the original tangent from the P. S_1 to the foot of the perpendicular PR, is represented by x. This distance is somewhat shorter than the distance CP measured along the curve: the difference in

length between CR and CP is called the x **correction**, and is given by the formula

$$x = CP - CR = .000762\,a^2\,l^5 \qquad (2)$$

This formula gives the quantity to be subtracted from CP, expressed in feet, to obtain the length CR in feet.

The values of y and the x correction, expressed in feet, corresponding to different points of the various spirals, are given in the sixth and seventh columns of Tables II to XV.

EXAMPLE.—To find the values of PR and CR to a point of the spiral 310 feet from the P. S_1 in the example of Art. **17**.

SOLUTION BY USING FORMULAS **1** AND **2**.—We have, in this example, $a = 2°$, $l = 3.1$, and from the small table in this article, using interpolation,

$$M = .003 + \tfrac{1}{5}(.010 - .003) = .004$$

Substituting these values in formula **1**,

$$y = .291 \times 2 \times 3.1^3 - 2^3 \times .004 = 17.31 \text{ ft.} \quad \text{Ans.}$$

Substituting known values in formula **2**,

$$x \text{ cor.} = .000762 \times 2^2 \times 3.1^5 = .9 \text{ ft.}$$

The distance $l = 310$ ft.; therefore, the distance $CR = 310 - .9 = 309.1$ ft. Ans.

SOLUTION BY USING THE TABLES.—From Table XI, in a horizontal line with $l = 310$ of the first column, we find $y = 17.31$ and x cor. $= .9$. Therefore, $PR = 17.31$ ft., and $CR = 310 - .9 = 309.1$ ft., as before.

EXAMPLES FOR PRACTICE

Find, from the tables, the distances PR and CR for the point indicated in each of the following four spirals:

1. $l = 400$ feet; $a = 1° 40'$. Ans. 30.92 ft. and 397.8 ft.
2. $l = 300$ feet; $a = 1°$. Ans. 7.85 ft. and 299.8 ft.
3. $l = 400$ feet; $a = 2°$. Ans. 37.04 ft. and 396.9 ft.
4. $l = 302$ feet; $a = 5°$. Ans. 39.61 ft. and 297.2 ft.

---

21. The Spiral Offset and the t Correction.—Let the circular curve BA, Fig. 8, be produced backwards until at a point E it becomes parallel to the original tangent—that is, until the tangent HW to the circular curve becomes parallel to $R'T$.

The point E at which a spiraled circular curve, if produced backwards, becomes parallel to the original tangent is called **the point of curve**, and is denoted by P. C.

The offset EV from the point of curve to the original tangent is called the **spiral offset.** The spiral offset is a very important distance in laying out the transition spiral. It is represented by F, and its value, in feet, is given by the formula

$$F = .072709\, a\, L^3 \qquad (1)$$

in which a = unit degree of curve of spiral;

L = whole length of spiral expressed in stations.

If M', Fig. 8, is the middle point of the spiral—that is, a point half way between the P. S_1 and the P. S_2—it will always be found that the spiral offset cuts the spiral at a point M that is a very short distance to the left of M'. The distance CV will therefore always be slightly less than the distance CM'. The difference between the half length of spiral CM' and the distance CV from the P. S_1 to the foot of the spiral offset is called the ***t* correction**; it is denoted by t, and its value, in feet, is given by the formula

$$t = CM' - CV = .000127\, a^2 L^5 \qquad (2)$$

This correction must be subtracted from the half length of spiral, expressed in feet, to obtain the distance CV, in feet.

The values of F and t are given in the fifth and eighth columns of the tables. The value of l in the first column, corresponding to which we find F and the t correction, is to be taken as the whole length of the spiral.

EXAMPLE.—To find the distances EV and CV for a spiral 400 feet long that connects with a 2° curve.

SOLUTION BY USING FORMULAS **1** AND **2**.—Here, $a = \frac{D}{L} = \frac{2°}{4} = \frac{1}{2}$. The whole length of spiral is 4 sta. Therefore, substituting in formula **1**,

$$F = .072709 \times \tfrac{1}{2} \times 4^3 = .072709 \times \tfrac{1}{2} \times 64 = 2.33 \text{ ft.} \quad \text{Ans.}$$

By formula **2**,

$$t \text{ correction} = .000127 \times \tfrac{1}{2}^2 \times 4^5 = .033 \text{ ft.}$$

Therefore,

$$CV = \tfrac{1}{2} \times 400 \text{ ft.} - .033 \text{ ft.} = 199.97 \text{ ft.} \quad \text{Ans.}$$

SOLUTION BY USING THE TABLES.—Since $a = \frac{1}{2}°$, Table II should be used. Since the whole length of spiral is 400 ft., we look along the same horizontal line with 400 of the first column, and find F = 2.33; t cor. = .03. Therefore, as before, EV = 2.33 ft., and CV = 199.97 ft. Ans.

EXAMPLES FOR PRACTICE

Find the spiral offset and the distance CV for each of the following four spirals:

1. $a = 1°$; length = 400 feet. Ans. 4.65 and 199.87 ft.
2. $a = 1° 40'$; length = 440 feet. Ans. 10.30 and 219.4 ft.
3. $a = 0° 30'$; length = 650 feet. Ans. 9.97 and 324.63 ft.
4. Spiral 500 feet long, connecting with a 4° curve. Ans. 7.26 and 249.75 ft.

---

22. The Middle Point of the Spiral Offset.—If M', Fig. 8, is the middle point of the spiral, and $M'K$ is its offset from the original tangent, it will be found that, even in the longest spirals, $M'K$ is almost exactly equal to one-half the spiral offset VE. The distance CK from the P. S_1 to the foot of $M'K$ is almost exactly equal to the distance CV from the P. S_1 to the foot of the spiral offset. Consequently,

The spiral offset and the spiral very nearly bisect each other; the point M at which the spiral cuts the offset is almost exactly half way between the P. C. and the original tangent.

A knowledge of this fact is of much use in the selection of spirals to fulfil given topographical conditions, as will be explained further on.

Example.—If the unit degree of curve of spiral is 1° 15', and the length of spiral is 500 feet, find the spiral offset VE, the offset KM' to the middle point of spiral, and the distances CV and CK from P. S_1 to the foot of these offsets.

Solution.—From Table IX, opposite the length 500 in the first column, we find $F = 11.33$ ft. Ans.

Since $CM' = 250$ ft., we find from the table, opposite 250 in the first column, $y = M'K = 5.67$ ft. Ans.

Thus, $M'K$ is almost exactly equal to $\frac{1}{2}$ VE. Similarly,

$$\left.\begin{array}{l} CV = 250 - .6 = 249.4 \text{ ft.} \\ CK = 250 - .1 = 249.9 \text{ ft.} \end{array}\right\} \text{Ans.}$$

TANGENT DISTANCES

23. Problem I.—*Given a spiraled circular curve, to find the distance from the point of intersection of the tangents to each P. S_1, when the lengths of the two spirals are equal.*

Let $R\,T$ and $R'\,T$, Fig. 9, be the two tangents intersecting in T. Let $A\,B$ be the circular curve, and $C\,A$ and $C'\,B$ the

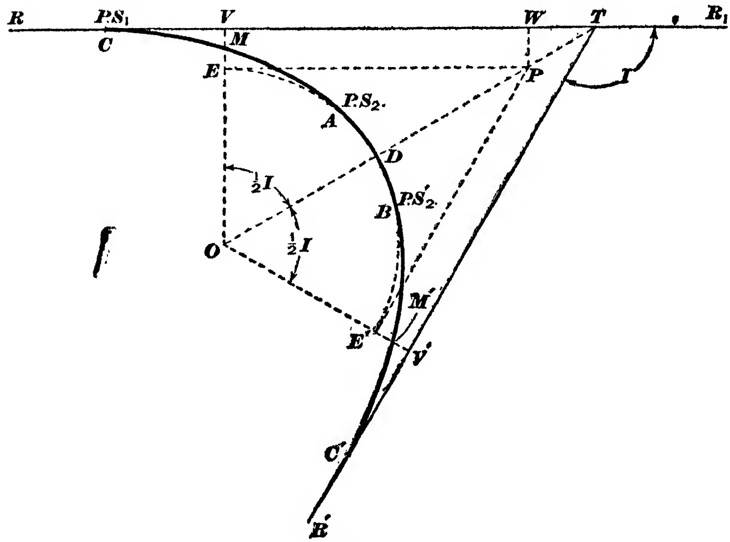


FIG. 9

two equal spirals. It is desired to find the distance $T\,C = T\,C'$.

Let O be the center of the arc $A\,B$. Draw $O\,V$ and $O\,V'$, perpendicular, respectively, to $R\,T$ and $R'\,T$, and produce $A\,B$ until it meets these lines in E and E'. These points are called, respectively, the point of curve P. C. (Art. **21**), and the **point of tangent** P. T. of the produced circular arc $A\,B$.

Draw $O\,T$. In the right triangles $V\,O\,T$ and $V'\,O\,T$, $O\,V = O\,V' = R + F$, and $O\,T$ is common to both triangles; therefore, the triangles are equal, and the angle $V\,O\,T = V'\,O\,T = \frac{1}{2}\,I$. Hence,

$$V\,T = V'T = O\,V \tan\tfrac{1}{2}I = (R+F)\tan\tfrac{1}{2}I$$

The desired distance is CT, which equals $VT + CV$; or, substituting for VT the value just found, and for CV the value ($\frac{1}{2}$ length of spiral $-\ t$ correction) (Art. **21**),

$$CT = C'T = \tfrac{1}{2} \text{ length} - t \text{ cor.} + (R + F) \tan \tfrac{1}{2} I$$

EXAMPLE.—A 6° curve is connected at both ends with the tangents by equal spirals, each 300 feet long. To find the distance from the point of intersection of the tangents to P. S_1 of each spiral, if the angle between the tangents is 80° 20′.

SOLUTION.—Here $a = 6 \div 3 = 2°$, and, therefore, Table XI should be used. In this table, opposite 300 in the first column, we find $F = 3.91$ ft., and t cor. = .1 ft.

The radius R of the circular curve is 5,730 ÷ 6 = 955 ft.; the half length of spiral is $\frac{1}{2} \times 300 = 150$ ft. Substituting these values in the foregoing formula,

$$CT = C'T = 150 - .1 + (955 + 3.91) \tan 40° 10' = 959.3 \text{ ft. Ans.}$$

24. Problem II.—*Given a spiraled circular curve, to find the distance from the point of intersection of the tangents to each P. S., when the lengths of the two spirals are not equal.*

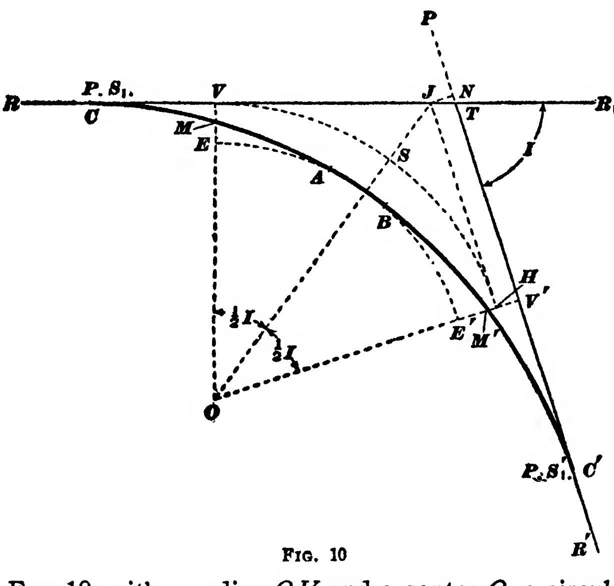


FIG. 10

If, Fig. 10, with a radius OV and a center O, a circular arc VSH is drawn, we shall have, exactly as in the last article,

$$VJ = JH = OV \tan \tfrac{1}{2} I = (R + F) \tan \tfrac{1}{2} I$$

If, from J, a perpendicular JN to the tangent $R'T$ is drawn, then $JN = HV' = E'V' - EV$. But $E'V'$ is the spiral offset to the second spiral, and EV is the spiral offset to the first spiral. Writing $E'V' = F'$ and $EV = F$, we have, therefore, $JN = F' - F$.

(*a*) *To Find the Distance CT.*—The figure gives

$$CT = CV + VJ + JT \qquad (1)$$

Now, $CV = \frac{1}{2} \times$ length $CA - t$ cor. (see Art. **21**); also, $VJ = (R + F) \tan \frac{1}{2} I$; and, from the small triangle JTN,

$$JT = \frac{JN}{\sin JTN} = \frac{JN}{\sin I} = \frac{F' - F}{\sin I}$$

Therefore, substituting these values in (1),

$$CT = \tfrac{1}{2} \text{ length of spiral} - t \text{ cor.}$$
$$+ (R + F) \tan \tfrac{1}{2} I + \frac{F' - F}{\sin I} \qquad \mathbf{(1)}$$

This formula gives the distance from the P. S_1 of the shorter spiral to the point of intersection of the tangents.

(*b*) *To Find the Distance C' T.*—The figure gives

$$C'T = C'V' + V'N - TN \quad (2)$$

Now, $C'V' = \frac{1}{2} \times$ length of second spiral $- t$ cor. for this spiral;

$$V'N = JH = (R + F) \tan \tfrac{1}{2} I;$$

and, in the triangle JTN,

$$TN = JN \cot JTN = (F' - F) \cot I$$

Therefore, substituting these values in (2),

$$C'T = \tfrac{1}{2} \text{ length of spiral} - t' \text{ cor.}$$
$$+ (R + F) \tan \tfrac{1}{2} I - (F' - F) \cot I \quad \mathbf{(2)}$$

This formula gives the distance from the P. S_1 of the longer spiral to the point of intersection of the tangents.

EXAMPLE.—Two tangents intersect at Sta. 820, and are to be connected with a 5° circular curve. The length of the first spiral is to be 250 feet, and that of the second is to be 400 feet; the angle between the tangents is 31° 48′. To find the station number of P. S_1, and the distance from the point of intersection of the tangents to P. S_1'.

SOLUTION.—The unit degree of curve of the first spiral is 5° ÷ 2.5 = 2°.
From Table XI, first spiral offset = F = 2.27 ft.
The unit degree of curve of the second spiral = 5° ÷ 4 = 1.25°.
From Table IX, second spiral offset = F' = 5.8 ft.

(*a*) *To find the tangent distance C T for the shorter spiral.*—Here, $R = 5{,}730 \div 5 = 1{,}146$ ft.; $F = 2.3$ ft.; and $I = 31° 48'$.

Therefore, $(R + F) \tan \frac{1}{2} I = (1{,}146 + 2.3) \tan 15° 54'$. = 327.1 ft.
Also, $(F' - F) \div \sin I = (5.8 - 2.27) \div \sin 31° 48'$ . . . = 6.7 ft.
And t cor. (Table XI) = .0; $\frac{1}{2}$ length − t cor. = 125 − .0 = 125.0

Therefore, the desired distance $C T$ . . . . = 458.8 ft. Ans.

The station number of P. S_1 will be 820 − (4 + 58.8) = 815 + 41.2. Ans.

(*b*) *To find the tangent distance C′ T for the longer spiral.*—
As before, $(R + F) \tan \frac{1}{2} I$ . . . . = 327.1 ft.
t cor. (Table IX) = .2; $\frac{1}{2}$ length − t cor. = 200 − .2 . . = 199.8

Sum = 526.9 ft.

$(F' - F) \cot I = (5.8 - 2.27) \cot 31° 48'$ . . . . = 5.7

Therefore, $C' T$ . . . . = 521.2 ft. Ans.

To find the two points of spiral in the field, it would therefore be only necessary to run the two tangents to their point of intersection, and then to measure back on the first tangent the distance 458.8 ft., and on the second tangent 521.2 ft.

EXAMPLES FOR PRACTICE

1. If a circular curve is connected with the two tangents by spirals of equal lengths, find the distance from the point of intersection of the tangents to the P. S_1, the data being as follows: length of spiral = 800 feet; degree of circular curve = 4°; angle between tangents = 65°. Ans. 1,323.4 ft.

2. Two tangents that intersect at an angle of 50° are to be connected with a 5° circular curve by spirals. The first spiral is to be 400 feet long and the second 500 feet. Find the distances from the point of intersection of the tangents to the P. S_1 of each spiral.
Ans. For 400-ft. spiral, 741.20 ft.; for 500-ft. spiral, 783.96 ft.

TO LAY OUT A SPIRAL IN THE FIELD

I. WHEN THE P. S$_1$ OF EACH SPIRAL IS VISIBLE FROM THE P. S$_2$

25. First Method.—Let RT and $R'T$, Fig. 11, be the two tangents that are to be connected with the circular curve AB by the two spirals CA and $C'B$. It will be assumed that the two spirals are of equal length.

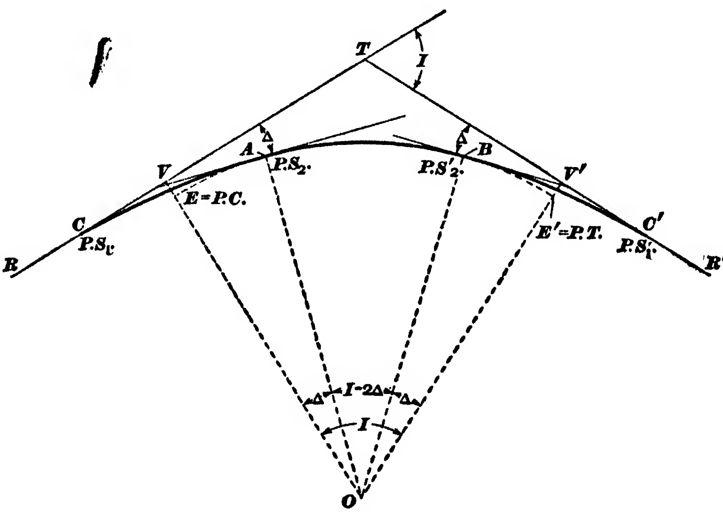


FIG. 11

Compute the unit degree of curve of spiral (Art. **12**); the spiral offset $VE = V'E'$ (Art. **21**); and the distance $CV = C'V'$ (Art. **21**); or obtain these quantities with the help of the tables, and compute the distance $CT = C'T$ (Art. **23**). Run the two tangents to their point of intersection T, measure back from T the distances TC and TC', and at C and C' set stakes marked P. S$_1$.

Set up the transit at P. S_1, sight on T, and then set stakes on the spiral exactly as on a simple circular curve, except that the deflection angle for each stake is computed by the formula in Art. **17**, or taken from the tables. When the stake at A (marked P. S_2) has been set, move the transit to A, backsight on P. S_1, and deflect from this direction the angle necessary to bring the telescope tangent to the simple circular curve at A. This angle is computed as explained in Art. **16.** Run in the circular curve as usual.

When the stake at B (marked P. S_2') has been set, move the transit to C', backsight on T, and stake out the second spiral in exactly the same manner as the first, using the deflection angles computed for the first spiral. When the last stake of $C'B$ has been set, backsight on T, and continue the survey along the tangent TR'.

EXAMPLE.—Two tangents that intersect at an angle of 80° 20′ are to be connected with a 6° circular curve by two equal spirals, each 300 feet long. The tangents intersect at Sta. 36. To lay out the two spirals and the circular curve.

SOLUTION.—(*a*) THE COMPUTATIONS.—In the example of Art. **23**, the following values were found for this curve:

Unit degree of curve of spiral = 2°; spiral offset = 3.91 ft.; $CV = C'V' = \frac{1}{2}$ length $- t$ cor. = 149.9 ft.; and $CT = C'T$ = 959.3 ft.

Since T is at Sta. 36, the station number of the P. S_1 is

$$36 - (9 + 59.3) = 26 + 40.7$$

It will be assumed that stakes are set 50 ft. apart on the spirals, and at the even stations on the circular curve.

Transit at P. S_1.—From Table XI, the following deflection angles are found:

to first stake,	0° 5′	(A) Angles to be deflected from the tangent. Vernier set at 0° 0′.
to second stake,	0° 20′	
to third stake,	0° 45′	
to fourth stake,	1° 20′	
to fifth stake,	2° 5′	
to P. S_2 at 29 + 40.7,	3° 0′	

From Table XI, deviation angle to P. $S_2 = \Delta = AOV$, Fig. 11, = 9° 0′. Therefore, central angle of circular curve is

$$80° 20' - 2 \times 9° = 62° 20'$$

The length of AB is therefore 62° 20′ ÷ 6 = 10.389 sta., and the station number of B is

$$29 + 40.7 + (10 + 38.9) = 39 + 79.6$$

By Art. **19**, the angle between the chord CA and the tangent to the circular curve at A is $\Delta - \theta = 9° - 3° = 6°$.

Transit at P. S_2.—The deflection angles to the stakes on the circular curve are as follows:

to Sta. 30, $.593 \times 3°$	= 1° 47′;	to Sta. 35,	16° 47′	(*B*) Angles to be deflected from tangent to circular curve. Vernier set at 6° 0′.
to Sta. 31,	4° 47′;	to Sta. 36,	19° 47′	
to Sta. 32,	7° 47′;	to Sta. 37,	22° 47′	
to Sta. 33,	10° 47′;	to Sta. 38,	25° 47′	
to Sta. 34,	13° 47′;	to Sta. 39,	28° 47′	
		to B,	31° 10′	

Transit at P. S_1'.—The angles to be deflected are the same as at P. S_1. The station number of P. S_1' is $(39 + 79.6) + 3 = 42 + 79.6$.

(*b*) The Field Work.—Run the two tangents to their intersection. Measure back from T the distances $TC = TC' = 959.3$ ft., and set stakes marked P. S_1 at C and C'. Set the transit at C with the vernier at 0° 0′; sight on T and deflect the angles (*A*) to locate the first spiral. When the stake at A (marked P. S_2) has been set, move to this point, set the vernier at 6° 0′, backsight on C, turn the telescope until the vernier reads 0° 0′, and from this direction deflect the angles (*B*) to locate the circular curve. When the stake at B (marked P. S_2) has been set, move the transit to C', set the vernier at 0° 0′, backsight on T, and deflect the angles (*A*) to locate the second spiral.

26. Second Method.—Another method consists in setting the transit over the point E, Fig. 11 (see Art. **21**), running in the entire circular curve from the P. C. to the P. T., setting stakes at each P. S_1 and P. S_2, and locating the spirals afterwards. The details of this method are as follows:

Run the tangents to their intersection, measure back the distances TC and TC' to locate each P. S_1, and set stakes marked P. S_1 at these points. Measure forwards the distances CV and $C'V'$, offset the distances VE and $V'E'$, and set stakes marked P. C. and P. T. at E and E', respectively.

Set the transit over E, bring the telescope parallel to RT, and run in the complete circular curve EE', setting stakes (marked P. S_2) at A and B, and on the curve between A and B. The angle $EOA = BOE' =$ the total deviation angle Δ, and therefore the angle of the circular curve AB is $I - 2\Delta$. Therefore, the distance EA is $\frac{\Delta}{D}$ stations; AB is $\frac{I - 2\Delta}{D}$ stations; and BE' is $\frac{\Delta}{D}$ stations.

The P. S$_1$ and P. S$_2$ of each spiral having been thus located, each curve is run in with the transit at its P. S$_1$, as described in Art. 25.

27. Spirals of Unequal Lengths.—Where a circular curve is to be spiraled at both ends, the two spirals should in all cases be chosen of equal lengths where this is possible. The unit degree of curve of spiral, the tangent distances CT and $C'T_2$, and all of the deviation and deflection angles will then be the same for both spirals, and but a single computation will be necessary for both curves. Sometimes, however, this selection is impossible. Generally, the longest spirals will give the easiest riding; but, where curves are numerous, in order to prevent overlapping, a spiral much shorter than is theoretically desirable must sometimes be chosen for one end of the circular curve.

The method of laying out two unequal spirals is the same in principle as that described for equal spirals, except that the computations must be made separately for each spiral.

II. WHEN THE P. S$_1$ IS NOT VISIBLE FROM THE P. S$_2$

28. Corresponding Points.—If P is any point of a spiral, then any two points whose distances from P are equal and which lie, one on the spiral and the other on the osculating circle at P, are called **corresponding points.**

Let P, Fig. 12, be any point of a spiral, and let $PM'N$ be the osculating circle to the spiral at this point. Let P' be a second point on the spiral, and P'' a point on the circle at the same distance from P, so that arc PP'' = arc PP'. Then, P' and P'' are corresponding points. Similarly, P_1' and P_1'' are corresponding points if arc PP_1' = arc PP_1''.

It is shown by advanced mathematics that the angle $P'PP''$ is equal to the deflection angle TCP''' to a point P''' on the spiral whose distance CP''' from C is equal to the distance PP' or PP''. Therefore, the angle $P'PP''$ can be readily computed or taken from the tables.

To find the angle between the tangent KPM and the chord PP', we have,

$$MPP' = MPP'' + P''PP'$$

But MPP'' is the deflection angle from the tangent to the circular curve $M'PN$; and, since $P''PP' = TCP'''$, we have the following rule for finding the angle that must be deflected from the tangent to the spiral at P to locate any second point P' of the spiral:

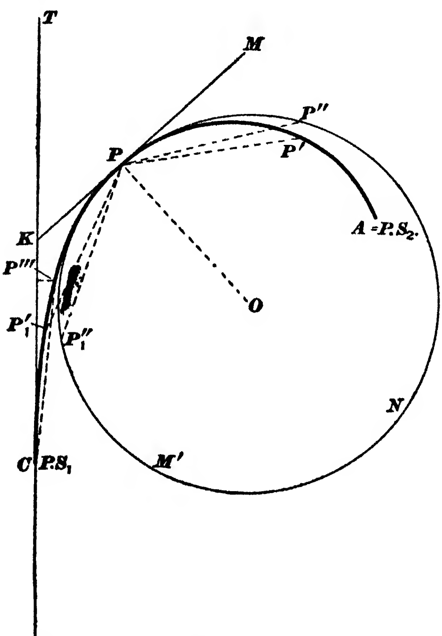


FIG. 12

Rule.—*Find the degree of curve of spiral at the point P (Art.* **12**)*; this is the same as the degree of curve of the circular arc PN of the osculating circle. Find the angle that would be deflected to locate the corresponding point on the osculating circle, and also the spiral deflection angle* TCP''' *to a point on the spiral whose distance from the P. S*$_1$ *is equal to* PP' *or* PP''*. If the point* P' *is between P and the P. S*$_2$*, add the last angle to the first; otherwise, subtract the last angle from the first: the result is the angle desired.*

The last part of the rule is evident from Fig. 12, since $KPP_1' = KPP_1'' - P_1'PP_1'' = KPP_1'' - TCP'''$, if $PP_1' = CP'''$.

EXAMPLE.—A spiral 600 feet long connects a tangent with a 6° curve. The P. S$_2$ is not visible from the P. S$_1$, so that the transit is moved forwards on the spiral to a point 300 feet from the P. S$_1$, and the telescope is brought tangent to the spiral at this point. It is required to compute the deflection angles necessary to locate this spiral, the stakes being set 100 feet apart.

SOLUTION.—The unit degree of curve of spiral is $6° \div 6 = 1°$. Therefore, Table VII, must be used.

The transit at P. S_1.—The deflections from the original tangent to locate stakes 1, 2, and 3 sta. from the P. S_1 are, from Table VII:

$$\left.\begin{array}{ll} \text{to first stake,} & 0°\ 10' \\ \text{to second stake,} & 0°\ 40' \\ \text{to third stake,} & 1°\ 30' \end{array}\right\}\text{Deflections from original tangent}$$

The transit 3 sta. from the P. S_1.—The degree of curve of spiral at this point, from Table VII, is 3° 0′. The stake 400 ft. from P. S_1 is 100 ft. from the transit point. The deflection angle to a point 100 ft. from the transit point on a simple circular curve is $\frac{1}{2} \times 1 \times 3° = 1°\ 30'$. The deflection angle from the P. S_1 to a point 100 ft. distant on the spiral, by Table VII, is 0° 10′. Since the point is between the transit point and the P. S_2, these two angles must be added, the result being 1° 40′. The complete results are as follows:

Station	Distance From Transit Point	Deflection Angle to 3° Circular Curve	Spiral Deflection Angle	Total Deflection Angle	
4	100	$\frac{1}{2} \times 1 \times 3° = 1°\ 30'$	0° 10′	1° 40′	
5	200	$\frac{1}{2} \times 2 \times 3° = 3°\ 0'$	0° 40′	3° 40′	Ans.
P. S_2	300	$\frac{1}{2} \times 3 \times 3° = 4°\ 30'$	1° 30′	6° 0′	

29. The principles of the preceding article enable one to compute the deflection angles necessary to locate either spiral with the transit at its P. S_2. When the telescope has been brought tangent to the spiral and the circular curve at this point, the angle KPP_1', Fig. 12, to be deflected to any stake is $KPP_1'' - P_1'PP_1''$ = (deflection angle to a point on the circular curve) − (spiral deflection angle).

In practice, however, it is better to run in the circular curve first, and then to locate each spiral from its P. S_1.

30. The Field Work.—Where the P. S_2 is not visible from the P. S_1, the complete circular curve should be run in from the P. C. to the P. T., as described in Art. **26**, and the spirals located afterwards. The only change in the field work is that introduced by the necessity of moving the transit forwards on the spiral.

The transit having been set up at some point P, Fig. 12, a backsight is taken on C, and the angle $KPC = \delta - \theta$ is deflected to bring the telescope tangent to the spiral (Art. **19**). Corresponding to the distance from P to each

stake between P and A, the circular deflection angles MPP'' are computed and the spiral deflection angles $P'PP'' = TCP'''$ added to them. The respective sums will be the angles MPP' that must be deflected from the tangent KM to locate the remaining stakes of the spiral.

EXAMPLE.—It is required to run in a spiral 800 feet long connecting with a 4° curve, the transit having been moved forwards to a stake 200 feet from the P. S_1. The stakes are to be set 100 feet apart.

SOLUTION.—Here $a = 4° \div 8 = \frac{1}{2}°$, and Table II should be used.

Transit at P. S_1.—From Table II,

deflection angle to first stake = 0° 5′
deflection angle to second stake = 0° 20′

Transit 200 ft. from P. S_1.—From Table II, $\delta = 1° 0'$ and $\theta = 20'$; therefore, the angle $KPC = 1° - 20' = 40'$. Also, d = degree of osculating circle = 1°.

The vernier is set at 0° 40′, a backsight is taken on C, and the telescope is turned until the vernier reads 0° 0′. From this direction, the following angles are deflected:

Stake	Distance From Transit Point	Deflections to a 1° Circular Curve	Spiral Deflections	Total Deflections
3	100	0° 30′	0° 5′	0° 35′
4	200	1° 0′	0° 20′	1° 20′
5	300	1° 30′	0° 45′	2° 15′
6	400	2° 0′	1° 20′	3° 20′
7	500	2° 30′	2° 5′	4° 35′
P. S_2	600	3° 0′	3° 0′	6° 0′

EXAMPLES FOR PRACTICE

In the following examples, the transit was moved forwards on the spiral. Find the angle KPC, Fig. 12, that must be deflected from the chord to the P. S_1 to bring the telescope tangent to the spiral, and also the angles that must be deflected from this direction to locate stakes 50 feet apart on the spiral between the transit point P and the P. S_2.

1. $D = 10°$; $L = 300$ feet, transit point 250 feet from P. S_1.

Ans. $\begin{cases} KPC = 6° 57' \\ \text{Deflection angles to P. } S_2 = 4° 13' \end{cases}$

2. $D = 10°$; $L = 600$ feet, transit point 400 feet from P. S_1.

Ans. $\begin{cases} KPC = 8° 53.5' \\ \text{Deflection angles, } 1° 44', 3° 36.5', 5° 37.5', \text{ and } 7° 46.5'. \end{cases}$

3. $D = 15°$; $L = 300$ feet, transit point 150 feet from P. S_1.

Ans. $\begin{cases} KPC = 3° 45' \\ \text{Deflection angles, } 2° 4.5', 4° 35', \text{ and } 7° 29.5'. \end{cases}$

INSERTING SPIRALS IN OLD TRACK

31. When it is desired to insert transition spirals in track that is already laid, the problem is essentially as follows:

There will be found on the roadbed two tangents $R V_1$ and $V_1' R'$, Fig. 13, that are connected by a simple circular curve $V_1 M_1 V_1'$. This curve is to be replaced by a new curve, either by offsetting the whole curve without increasing its degree of curve, as shown in Fig. 13, or else by sharpening

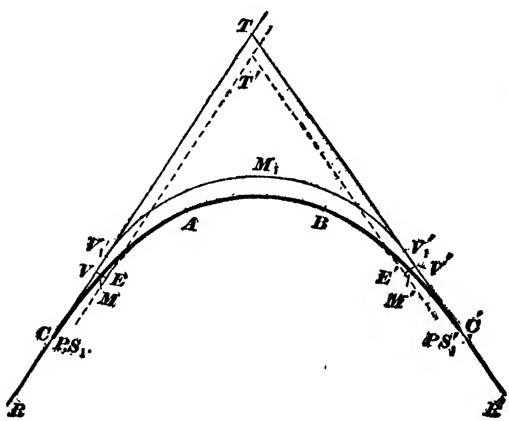


FIG. 13

the old curve, as shown in Figs. 14 and 15, so that the tangents $E T'$ and $E' T'$, Fig. 13, to the new curve may be offset from the old tangents, and thus give room for the introduction of transition spirals $C M A$ and $C' M' B$.

If the degree of the new circular curve $E A B E'$ is made the same as the degree of the old curve $V_1 M_1 V_1'$, the effect will be the same as moving the whole curve $V_1 M_1 V_1'$ downwards until it is brought tangent to the lines $E T'$ and $E' T'$ at the points E and E'. The entire length of the old track will thus be changed from its old position, and nearly all of

it will be moved by the whole amount of the spiral offset VE or $V'E'$. This method of replacing the old curve is, therefore, not usually advisable unless the offsets are small or the curve very short. In nearly every case, it will be better to sharpen the old curve in such a manner that, while the track is moved as little as possible on the roadbed, the new tangents ET' and $E'T'$ will still fall a sufficient distance inside of the old ones.

The distances VE and VE' from the old to the new tangents are the same as the spiral offsets of the two spirals. They depend for their value on the degree of the new circular curve and on the lengths chosen for the spirals (Art. **21**). The best length to be taken for a spiral will be determined by the speed of the trains that pass over the track and by the degree of the new circular curve; but this theoretically best length must often be modified by topographical conditions. In any particular case, the engineer has, therefore, to select the spirals and the new degree of the circular curve in such a manner that these quantities will approach as nearly as possible the values that are theoretically the best, and yet so that the old track will not be displaced more than is advisable on the roadbed. This subject will be treated more fully further on.

32. The successive steps in inserting spirals in old track are as follows:

1. Ascertain the degree of curve of the old circular curve $V_1 M_1 V_1'$, Fig. 13.

2. Select the spirals to be inserted and the new degree of circular curve; compute the spiral offsets VE and $V'E'$ (Art. **21**), the distances VC and $V'C'$ (Art. **22**), and the distances TC and TC' (Arts. **23** and **24**).

3. Locate the P. S.$_1$ and run in each spiral as already explained. If the point T is inaccessible, the P. S.$_1$ may be located by measuring back from the old P. C. the distance $V_1 C$, which equals $TC - TV_1$, in which TC is computed as in Arts. **23** and **24**, and TV_1 is the tangent distance to the old (unspiraled) curve.

33. External to a Circular Curve.—The **external distance**, or, for shortness, the **external**, of a circular curve, is the distance, measured along a radial line, between the point of intersection of the tangents and the curve. Thus, in Fig. 9, the external to the circular curve EDE' is PD. The figure gives, denoting the radius by R, and the external by q,

$$q = PD = OP - OD = OE \sec \tfrac{1}{2} I - R = R \sec \tfrac{1}{2} I - R;$$

or, finally,

$$q = R(\sec \tfrac{1}{2} I - 1) = \frac{2R \sin^2 \frac{1}{4} I}{\cos \frac{1}{2} I} \qquad (1)$$

The difference between the secant of an angle and 1 is called the **external secant** of the angle. Some field books give tables of both natural and logarithmic external secants. The abbreviation *exsec*, read *exsecant*, is used for external secant. Formula **1** may, therefore, be written

$$q = R \operatorname{exsec} \tfrac{1}{2} I \qquad (2)$$

If no table of exsecants is available, $\sec \frac{1}{2} I - 1$, or its equivalent $\frac{2 \sin^2 \frac{1}{4} I}{\cos \frac{1}{2} I}$ (the latter being preferable for logarithmic work), may be used instead of exsec I. Tables are also given in some books, from which external distances (values of q) can be taken directly.

34. External to a Spiraled Circular Curve, the Spirals Being Equal.—The external to a spiraled circular curve is the distance TD, Fig. 9, between the curve and the intersection of the tangents to the spirals. Denoting the external by q_1, the figure gives

$$q_1 = PD + PT = q + PW \sec WPT$$
$$= q + PW \sec \tfrac{1}{2} I = q + EV \sec \tfrac{1}{2} I;$$

or, since $EV = F$ (Art. **21**),

$$q_1 = q + F \sec \tfrac{1}{2} I \qquad (1)$$

If a table of externals for circular curves is available, q may be taken from it. If not, the value of q_1 may be written, by replacing the value of q from formula **1**, Art. **33**,

$$q_1 = R(\sec \tfrac{1}{2} I - 1) + F \sec \tfrac{1}{2} I;$$

or

$$q_1 = (R + F) \sec \tfrac{1}{2} I - R \qquad (2)$$

EXAMPLE.—A 6° curve is connected at both ends with the tangents by spirals 300 feet long. To find the external to the spiraled curve, if the angle between the tangents is 80° 20′.

SOLUTION.—From the table of radii and deflections in *Circular Curves*, the radius of a 6° curve is found to be 955.37 ft.

The unit degree of curve of spiral is 6° ÷ 3 = 2°; therefore, from Table XI, F = 3.91 ft. Substituting these values in formula **2**,

$$q_1 = (955.37 + 3.91) \sec 40° 10' - 955.37 = 299.9 \text{ ft. Ans.}$$

35. Problem.—*To find the length of the transition spiral when the degree of the circular curve and the spiral offset are given.*

From formula **1**, Art. **21**, we have $F = .072709\, a\, L^3$, and from formula **3**, Art. **12**, $a = \frac{D}{L}$. Substituting this value of a in the first formula,

$$F = .072709\, L^2 D \qquad (1)$$

Solving for L,

$$L = \sqrt{\frac{F}{.072709\, D}} = 3.7086 \sqrt{\frac{F}{D}} \qquad (2)$$

EXAMPLE.—What length of spiral will give a spiral offset of 11 feet, if the degree of the circular curve is 7° 30′?

SOLUTION.—Substituting F = 11 and D = 7.5 in formula **2**,

$$L = 3.7086 \times \sqrt{\frac{11}{7.5}} = 4.49 \text{ sta.} = 449 \text{ ft. Ans.}$$

A spiral 450 ft. long would be chosen. The throw of the old track at the P. C. (Fig. 8) is the distance VM, which would then be about 5½ ft. (Art. **22**).

EXAMPLES FOR PRACTICE

1. A 5° curve is connected at both ends with the tangents by spirals 400 feet long. What is the external to the spiraled curve, if the angle between the tangents is 75° 36′? Ans. 311.9 ft.

2. Find the length of spiral that will produce the spiral offset indicated when the spiral joins each of the following curves with the tangent. (*a*) D = 2° 24′; F = 1 foot; (*b*) D = 4° 6′; F = 5 feet; (*c*) D = 3° 30′; F = 2 feet; (*d*) D = 8° 30′; F = 16 feet.

Ans. (*a*) 239 ft. (*b*) 410 ft. (*c*) 280 ft. (*d*) 509 ft.

SELECTION OF SPIRALS

36. The Best Length of Spiral.—Equation (1), Art. **13**, is $e = .000058\,a\,L\,V^2$. This equation gives the total superelevation attained by the outer wheels in passing over the whole spiral. The best length of spiral should be such that, for all spirals and their corresponding train speeds, the time occupied by the outer wheels in attaining a given superelevation shall be constant; that is, the superelevation attained by the outer wheels during, for example, 1 second should be the same for all curves and spirals.

Let T be the time, in hours, occupied by the train in passing over the whole spiral; then

$$T = \frac{L}{52.80\,V}$$

since there are 52.80 stations in 1 mile. The time T is the number of hours required by the outer wheels to attain a superelevation e. The superelevation attained in one unit of time will therefore be

$$\frac{e}{T} = .000058\,a\,L\,V^2 \div \frac{L}{52.80\,V} = .000058 \times 52.80 \times a\,V^3$$

Since this superelevation attained in a unit of time is to be a constant for all spirals, $a\,V^3$ must be a constant. We may therefore write

$$a\,V^3 = K$$

in which K is some constant quantity whose value is to be determined.

It is found from experience that, when $V = 60$ miles per hour, the best spiral is probably that in which $a = \frac{1}{2}°$. Therefore, substituting $\frac{1}{2}$ for a and 60 for V, we obtain $K = \frac{1}{2} \times (60)^3$. By finally replacing this value of K, and solving for a, we find

$$a = \frac{1}{2} \times \left(\frac{60}{V}\right)^3$$

This formula gives the value of a for the easiest riding when the maximum train velocity V is known. If this value of a is substituted in the formula $L = \frac{D}{a}$ (Art. **12**), the resulting value of L will be the best length of spiral.

EXAMPLE.—To find the theoretically best length of spiral to connect with a 6° curve, the maximum train velocity being 40 miles per hour.

SOLUTION.—Substituting $V = 40$ in the formula for a, we get

$$a = \frac{1}{2} \times \left(\frac{60}{40}\right)^3 = \frac{1}{2} \times \frac{27}{8} = \frac{27}{16}^\circ$$

Therefore, $L = 6 \div \frac{27}{16} = 3.5556$ sta. $= 355.6$ ft. Ans.

37. Table of Minimum Spiral Lengths.—The accompanying table, from Talbot's "Transition Spiral," gives the values of a corresponding to the *least length of spiral* that the engineer should endeavor to insert. The spiral may be longer than the length obtained from this table, but it should not be shorter, unless topographical conditions make it necessary to use a shorter spiral than the minimum given in the table.

Maximum Train Speed Miles per Hour	Unit Degree of Curve of Spiral
75	30′ or less
60	30′ or less
50	1° or less
40	2° or less
30	3° 20′ or less
25	5° or less
20	10° or less

The least length corresponding to any value of a is found from the formula $L = \frac{D}{a}$.

EXAMPLE.—To find the least length for the spiral in the example of the preceding article.

SOLUTION.—The velocity is 40 mi. per hr.; therefore, from the table, $a = 2°$, and $L = 6° \div 2 = 3$ sta. $= 300$ ft. Ans.

EXAMPLES FOR PRACTICE

Find the best length of spiral and also the least length that should be selected in each of the following examples:

1. $V = 75$; $D = 2°$. Ans. 781 and 400 ft.
2. $V = 40$; $D = 7°$. Ans. 415 and 350 ft.
3. $V = 30$; $D = 10°$. Ans. 250 and 300 ft.

NOTE.—From the answers to example 3, the student will notice that the theoretically best lengths for very sharp curves and low speeds may be less than the least lengths advised by Talbot. The practice of engineers in selecting spirals for such speeds differ widely.

38. Problem.—*To select a spiral and a new circular curve so that the vertex of the old curve shall not be moved on the roadbed.*

Let $V_1 D V_1'$, Fig. 14, be the old curve, and let $CABC'$ be the new spiraled curve. The vertex D is not to be moved.

Let $q = TD =$ external to old unspiraled curve;

$q' = PD =$ external to new (unspiraled) circular curve;

$q_1 =$ external to new spiraled curve.

Then, $q_1 = TD = q$, since the vertex is not moved. Let R

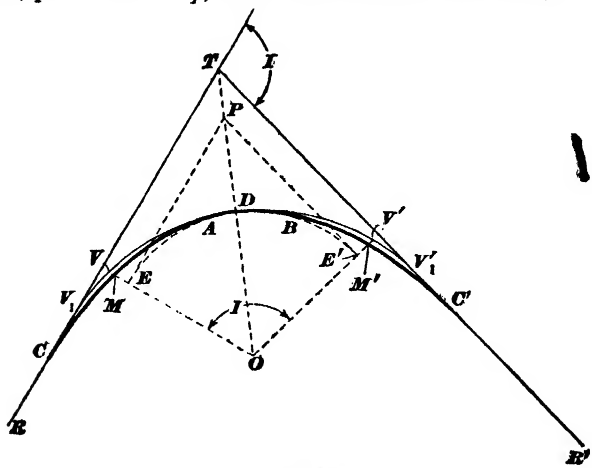


FIG. 14

and R' be the radii of the old and new circular curves, respectively.

From formula **1**, Art. **34**,

$$q_1 = q' + F \sec \tfrac{1}{2} I;$$

or, since $q_1 = q$,

$$q = q' + F \sec \tfrac{1}{2} I;$$

whence

$$q' = q - F \sec \tfrac{1}{2} I \qquad (1)$$

The external q to the old curve can be computed (Art. **33**), taken from a table, or measured on the ground. If a value F is then assumed, formula **1** will give the external q' to the new circular curve. Having q', the radius R' of the new

circular curve is taken from a table of externals or is computed by means of formula **1**, Art. **33**, which gives

$$R' = \frac{q'}{\sec \frac{1}{2} I - 1} = \frac{q'}{\operatorname{exsec} \frac{1}{2} I} \qquad (2)$$

The degree of curve can now be found, and from it and F the value of L is computed by formula **2**, Art. **35**. The spiral may then be laid out on the ground as described in Art. **25**.

39. It will be observed that, in the method of the preceding article, the length of spiral and the new degree of curve were determined entirely by the value chosen for the spiral offset F, or VE. It will very seldom be the case, however, that the amount of this offset must be exactly fixed to satisfy conditions on the ground, though this might be the case if the curve were in a tunnel that could not be widened, or at the entrance to a bridge. A more practical method is as follows: The degree of the curve $V_1 D V_1'$ having been given, a value is assumed for the length of spiral best adapted to this curve (see Arts. **36** and **37**). Then the unit degree of curve of spiral (Art. **12**), and the spiral offset (Art. **21**) are computed. These quantities cannot be exactly determined, because the spiral does not connect with the curve $V_1 D V_1'$, but with the curve EDE', and the degree of EDE' is not yet known. But if it is assumed that the degree of EDE' is the same as that of VDV', a value of VE will be obtained that will be sufficiently close to the true value to enable the engineer to judge whether the offset that will finally result will be too large or not. If it is inadvisable to throw the track so great a distance as the value of VM corresponding to the length of spiral chosen, a new length of spiral must be assumed, and a new spiral offset computed. Formula **1**, Art. **35**, shows that the smaller L is, the less F will be, and therefore that *shortening the spiral decreases the spiral offset.* Successive smaller values for L must be tried until a length is found that leads to an admissible value of VM. With this value of L, and the corresponding approximate value of F, the new degree of curve is computed as in Art. **38**.

Having L and the degree of curve of $EABE'$, the value of F is accurately computed, and the curve and spirals are located as described in Art. **31.**

EXAMPLE.—Two tangents that intersect at an angle of 40° are connected by a 5° circular curve. It is required to select spirals for this curve if the vertex is not to be moved, nor the old track moved at any point more than .7 foot on the roadbed, assuming the maximum train speed to be 50 miles per hour.

SOLUTION.—Since VM, Fig. 14, cannot exceed .7 ft., the spiral offset VE must not be greater than about 1.4 ft. (Art. **22**).

From the formula of Art. **36,** the best length of spiral will be

$$5 \div \tfrac{1}{2} \times (\tfrac{60}{50})^3 = 5 \div \tfrac{216}{250} = 579 \text{ ft.}$$

As the spiral offset must be so small, this spiral would evidently be too long. Spirals shorter than this will be assumed and tested.

First assumption: length = 500 ft. Then, a = 1°, and F (Table VII) = 9.07 ft. A length of 500 ft. is therefore too great.

Second assumption: length = 300 ft. Then, a = 1° 40′, and F (Table X) = 3.26 ft. The spiral is still too long.

Third assumption: length = 200 ft. Then, a = 2° 30′, and F (Table XII) = 1.45 ft. A length of 200 ft. may therefore be taken for the spiral.

Computation of the degree of the spiraled curve.—From a table of radii and deflections, the radius of a 5° curve is found to be 1,146.3 ft. Substituting known values is formula **1,** Art. **33,**

$$q = 1{,}146.3 \ (\sec 20° - 1) = 73.478 \text{ ft.}$$

Substituting this value of q in formula **1,** Art. **38,**

$$q' = 73.478 - 1.45 \sec 20° = 71.935 \text{ ft.}$$

Finally, substituting this value of q' in formula **2,** Art. **38,**

$$R' = \frac{71.935}{\sec 20° - 1} = 1{,}122.2 \text{ ft.}$$

The degree of curve corresponding to this radius is 5° 6′. The old curve is thus sharpened slightly. We have, then, a = 5.1° ÷ 2 = 2.55°; and (formula **1,** Art. **21**)

$$F = .072709 \times 2.55 \times 2^3 = 1.48 \text{ ft.}$$

The final selection will therefore be as follows:

$$\left.\begin{array}{ll} \text{Degree of new curve} & = 5° \ 6' \\ \text{Length of spiral} & = 200 \text{ ft.} \\ \text{Spiral offset} & = 1.48 \text{ ft.} \end{array}\right\} \text{Ans.}$$

This is too short a spiral for the train speed given, but it cannot be lengthened without increasing the spiral offset.

40. Problem.—*To select a spiral and the new circular curve so that the old track shall be moved as little as possible on the roadbed.*

The new track must be made to pass as far outside the old track at the vertex as it is offset from the old track at the new P. C. That is, the distance HD, Fig. 15, must be made

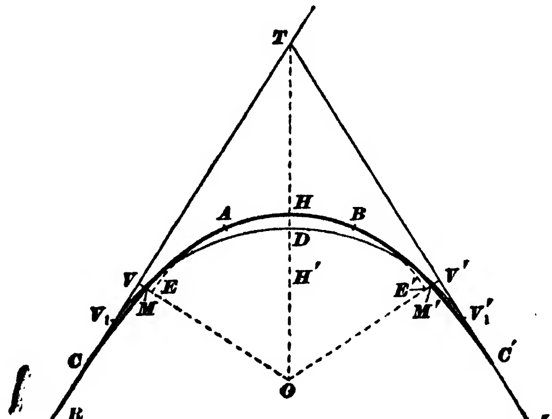


FIG. 15

equal to $VM = \frac{F}{2}$. The new external distance TH must, therefore, equal the old external distance TD diminished by $\frac{F}{2}$. Therefore if the new external distance is q', we have

$$TH = q' = TD - \frac{F}{2}$$

But, by formula **1**, Art. **38**,

$$TD = q - F \sec \tfrac{1}{2} I$$

Therefore,

$$q' = q - F \sec \tfrac{1}{2} I - \frac{F}{2}$$

In applying this formula, the greatest allowable offset VM, or $\frac{F}{2}$, is first selected, and then the external q to the old curve is computed or taken from a table. The radius and degree of the new curve are found as explained in Art. **38**, the length of spiral by formula **2**, Art. **35**, and the unit degree of curve of spiral by the usual formula $a = \frac{D}{L}$.

EXAMPLE.—In the example of Art. **39**, to select the new degree of curve and the spiral, supposing that the vertex may be moved.

SOLUTION.—The track may be thrown .7 ft. at the new P. C.; therefore (Art. **22**), $F = 1.4$ ft. The external to the old curve was found to be 73.478 ft. Therefore, by the formula in this article,

$$q' = 73.478 - 1.4 \sec 20° - .7 = 73.478 - 1.49 - .7 = 71.288 \text{ ft.}$$

The degree of the new curve, either computed or taken from a table, is 5° 9′, nearly.

The length of spiral (formula **2**, Art. **35**) is

$$3.7086 \times \sqrt{\frac{1.40}{5.15}} = 1.934 \text{ sta.} = 193.4 \text{ ft.}$$

The theoretical selection will therefore be as follows:

$$\left.\begin{array}{ll} \text{Degree of new curve} & = 5° \, 9' \\ \text{Length of spiral} & = 193.4 \text{ ft.} \\ \text{Spiral offset} & = 1.4 \text{ ft.} \end{array}\right\} \text{Ans.}$$

The practical selection would probably be $D = 5° \, 7'$, length = 192 ft.; a would then be 2° 40′, and the spiral offset, 1.37 ft.

41. Problem.—*To select a spiral and a new circular curve so that the old track shall be offset a given distance at the new P. C. and also moved a given distance either in or out at the vertex.*

Let VM, Fig. 15, be the distance that the track may be moved in at the new P. C., and let p ($= HD$) be the distance that it may be moved out at the vertex. Then, $VM = \frac{F}{2}$.

The external TH to the new spiraled curve will then be (Art. **40**),

$$TH = q' - F \sec \tfrac{1}{2} I - p \qquad (1)$$

If the new track is to fall inside of the old track at the vertex, let H' be the position of the new vertex, and let $DH' = p'$. The external TH' to the new curve will then be

$$TH' = q' - F \sec \tfrac{1}{2} I + p' \qquad (2)$$

If, therefore, q' is computed, and if F and either p or p' is assumed, formulas **1** and **2** will give the value of the new external TH or TH'. From this, the new degree of curve is found, and the solution of the problem is completed exactly as in Arts. **39** and **40**.

EXAMPLE.—A 4° circular curve joins two tangents that intersect at an angle of 30° 20′. It is required to select a new curve and spirals that shall throw the old track out 1 foot at the vertex and .8 foot in at the new P. C.

SOLUTION.—Formula **1** is to be used. The external q' to the old 4° curve is found to be 51.72 ft. Also, $F = 2 \times .8 = 1.6$ ft. (Art. **22**), and $p = 1$. Therefore, substituting these values in formula **1**, the external to the new curve is

$$TH = 51.72 - 1.6 \times \sec 15° 10' - 1 = 49.06 \text{ ft.}$$

The degree of the new curve is found, either by computation or from a table of externals, to be 4° 13′.

By formula **2**, Art. **35**,

$$L = 3.7086 \times \sqrt{\frac{1.6}{4.217}} = 2.284 \text{ sta.} = 228.4 \text{ ft.}$$

The theoretical selection is, therefore,

$$\left.\begin{array}{ll} \text{New degree of curve} & = 4° 13' \\ \text{Length of spirals} & = 228.4 \text{ ft.} \\ \text{Spiral offsets} & = 1.6 \text{ ft.} \end{array}\right\} \text{Ans.}$$

In practice, the selection would probably be $D = 4° 13'$, length = 211 ft.; a would then be 2° and Table XI could be employed. The resulting spiral offset would be 1.37 ft.

EXAMPLES FOR PRACTICE

A 3° 30′ curve joins two tangents that intersect at an angle of 26° 20′. Select a new curve and spiral, if the old track may be thrown by the amounts indicated in the following examples (the answers given are the theoretical selections):

1. Thrown out 2 feet at the vertex and in $1\frac{1}{2}$ feet at the new P. C.
Ans. Length = 323.2 ft.; degree of new circular curve = 3° 57′

2. Thrown in $1\frac{1}{2}$ feet at the new P. C.; the vertex must not be moved. Ans. Length = 330.8 ft.; D = 3° 46′

---

42. Remarks on the Selection of Spirals.—The student will readily understand that it is impossible to give exact rules for the best selection of spirals. Having located the old P. C. and P. T., and having run over the center line of the old track, the engineer should study the location thus obtained and decide how it may be modified to allow the insertion of transition spirals. He should always try a few different values for the throw at the vertex and at the new P. C., in order to see how the varying of these quantities will affect the new degree of curve and the length of spiral. In many cases he will find that the necessity of keeping the new track on the old roadbed will make it necessary to insert shorter spirals than are theoretically best.

TABLE I

SUPERELEVATION (FEET) OF OUTER RAIL ON CURVES

Degree of Curve Degrees	Velocity, in Miles per Hour											
	10	15	20	25	30	35	40	45	50	60	70	75
1	.006	.013	.023	.036	.051	.070	.091	.116	.143	.206	.283	.325
2	.011	.026	.046	.071	.103	.140	.183	.231	.285	.410	.567	.650
3	.017	.039	.069	.107	.154	.210	.274	.346	.427	.612	.842	
4	.023	.051	.091	.143	.206	.280	.365	.461	.568	.811	1.125	
5	.029	.064	.114	.179	.257	.349	.455	.574	.707	1.006		
6	.034	.077	.137	.214	.308	.418	.545	.687	.844	1.196		
7	.040	.090	.160	.250	.359	.487	.634	.798	.979			
8	.046	.103	.183	.285	.410	.556	.723	.908	1.112			
9	.051	.116	.206	.320	.460	.624	.811	1.017				
10	.057	.129	.228	.356	.511	.692	.898	1.124				
11	.063	.142	.251	.391	.561	.760	.984					
12	.069	.154	.274	.427	.611	.826	1.069					
14	.080	.180	.319	.497	.711	.959						
16	.091	.206	.365	.567	.809	1.088						
18	.102	.231	.410	.637	.906							
20	.114	.256	.455	.707	1.002							
25	.141	.318	.563	.775								
30	.168	.380	.672	.844								
35	.195	.441	.778									
40	.222	.501	.881									
50	.276	.618										

TABLE II

TRANSITION SPIRAL

a = 0° 30′. 1° in 200 feet

l	*d*	*δ*	*θ*	*F*	*y*	*x* cor.	*t* cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
25	0 7.5	0 0.9	0 0.3	.00	.00	.00	.00
50	15	3.8	1.3	.00	.02	.01	.00
75	22.5	8.4	2.8	.02	.06	.00	.00
100	30	15	5	.04	.15	.00	.00
125	0 37.5	0 23.4	0 7.8	.07	.29	.00	.00
150	45	33.8	11.3	.12	.49	.00	.00
175	52.5	45.9	15.3	.20	.78	.00	.00
200	1 00	1 00	20	.29	1.16	.01	.00
225	1 7.5	1 15.9	0 25.3	.41	1.66	.01	.00
250	15	33.8	31.3	.57	2.27	.02	.00
275	22.5	53.4	37.8	.76	3.03	.03	.01
300	30	2 15	45	.98	3.93	.05	.01
325	1 37.5	2 38.4	0 52.8	1.25	5.00	.07	.01
350	45	3 3.8	1 1.3	1.56	6.23	.10	.02
375	52.5	30.9	10.3	1.92	7.67	.14	.02
400	2 00	4 00	20	2.33	9.31	.19	.03
425	2 7.5	4 30.9	1 30.3	2.79	11.16	.26	.04
450	15	5 3.8	41.3	3.31	13.25	.35	.06
475	22.5	38.4	52.8	3.89	15.58	.46	.08
500	30	6 15	2 5	4.54	18.16	.59	.10
525	2 37.5	6 53.4	2 17.8	5.26	21.03	.75	.13
550	45	7 33.8	31.3	6.04	24.17	.95	.16
575	52.5	8 15.9	45.3	6.91	27.62	1.20	.20
600	3 00	9 00	3 00	7.84	31.36	1.48	.24
625	3 7.5	9 45.9	3 15.3	8.87	35.45	1.81	.30
650	15	10 33.8	31.3	9.97	39.85	2.21	.37
675	22.5	11 23.4	47.8	11.16	44.63	2.66	.44
700	30	12 15	4 4.9	12.45	49.73	3.20	.53
725	3 37.5	13 8.4	4 22.7	13.83	55.22	3.81	.64
750	45	14 3.8	41.2	15.30	61.09	4.51	.75
775	52.5	15 0.9	5 00.1	16.88	67.37	5.31	.89
800	4 00	16 0	19.8	18.56	74.05	6.22	1.04

TABLE III

TRANSITION SPIRAL

$a = \frac{4^\circ}{7}$. *1° in 175 feet*

l	*d*	*δ*	*θ*	*F*	*y*	*x* cor.	*t* cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
25	0 8.6	0 1.1	0 0.4	.00	.00	.00	.00
50	17.1	4.3	1.4	.00	.02	.00	.00
75	25.7	9.6	3.2	.02	.07	.00	.00
100	34.3	17.1	5.7	.04	.17	.00	.00
125	0 43.9	0 26.7	0 8.9	.08	.32	.00	.00
150	51.4	38.6	12.9	.14	.56	.00	.00
175	1 0	52.5	17.5	.22	.89	.00	.00
200	8.6	1 8.6	22.9	.33	1.33	.01	.00
225	1 17.1	1 26.8	0 28 9	.47	1 89	.01	.00
250	25.7	47.2	35.7	.65	2.59	.02	.00
275	34.3	2 9.7	43.2	.86	3.45	.04	.01
300	42.9	34.4	51.5	1.12	4.48	.06	.01
325	1 51.4	3 1.1	1 00.4	1.42	5.70	.09	.02
350	2 0	30	10	1.78	7.12	.13	.02
375	8.6	4 1.1	20.4	2.19	8.76	.19	.03
400	17.1	34.4	31.5	2.66	10.63	.26	.04
425	2 25.7	5 9.8	1 43.3	3.18	12.74	.35	.06
450	34.3	47.3	55.8	3.78	15.11	.46	.08
475	42.9	6 26.9	2 9	4.44	17.78	.60	.10
500	51.4	7 8.7	22.9	5.19	20.73	.77	.13
525	3 0	7 52.7	2 37.5	6.00	24.00	.99	.17
550	8.6	8 38.8	52.9	6.90	27.58	1.25	.21
575	17.1	9 27	3 9	7.89	31.47	1.56	.26
600	25.7	10 17.4	25.8	8.96	35.79	1.93	.32
625	3 34.3	11 9.9	3 43.2	10.13	40.44	2.36	.39
650	42.9	12 4.6	4 1.4	11.39	45.47	2.87	.48
675	51.4	13 1.4	20.4	12.74	50.89	3.47	.57
700	4 0	14 0.4	40	14.22	56.76	4.15	.69
725	4 8.6	15 1.5	5 00.3	15.80	63.08	4.99	.83
750	17.1	16 4.7	21.4	17.48	69.81	5.91	.98
775	25.7	17 10.1	43.2	19.29	76.99	6.95	1.17
800	34.3	18 17.6	6 5.6	21.21	84.63	8.14	1.36

TABLE IV

TRANSITION SPIRAL

$a = 0° 40'$. $1°$ in 150 feet

l	d	δ	θ	F	y	x cor.	t cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
25	0 10	0 1.3	0 0.4	.00	.00	.00	.00
50	20	5	1.7	.01	.02	.00	.00
75	30	11.3	3.8	.02	.08	.00	.00
100	40	20	6.7	.05	.19	.00	.00
125	0 50	0 31.3	0 10.4	.10	.38	.00	.00
150	1 00	45	15	.16	.65	.00	.00
175	10	1 1.3	20.4	.26	1.04	.01	.00
200	20	20	26.7	.39	1.55	.01	.00
225	1 30	1 41.3	0 33.8	.55	2.21	.02	.00
250	40	2 5	41.7	.76	3.03	.03	.01
275	50	31.3	50.4	1.01	4.04	.05	.01
300	2 00	3 00	1 00	1.31	5.23	.08	.01
325	2 10	3 31.3	1 10.4	1.66	6.66	.12	.02
350	20	4 5	21.7	2.08	8.31	.18	.03
375	30	41.3	33.8	2.56	10.23	.25	.04
400	40	5 20	46.7	3.10	12.40	.35	.06
425	2 50	6 1.3	2 .4	3.72	14.88	.47	.08
450	3 00	45	15	4.41	17.66	.62	.10
475	10	7 31.3	30.4	5.19	20.76	.82	.14
500	20	8 20	46.7	6.05	24.20	1.06	.18
525	3 30	9 11.3	3 3.8	7.01	28.02	1.35	.22
550	40	10 5	21.7	8.05	32.19	1.70	.28
575	50	11 1.3	40.4	9.20	36.78	2.12	.36
600	4 00	12 0	59.9	10.45	41.76	2.63	.44
625	4 10	13 1.3	4 20.3	11.83	47.20	3.22	.54
650	20	14 5	41.6	13.29	53.05	3.93	.66
675	30	15 11.3	5 3.6	14.88	59.41	4.73	.78
700	40	16 20	26.4	16.60	66.20	5.69	.94

TABLE V

TRANSITION SPIRAL

a = 0° 48′. 1° in 125 feet

l	d	δ	θ	F	y	x cor.	t cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
25	0 12	0 1.5	0 0.5	.00	.00	.00	.00
50	24	6	2	.01	.03	.00	.00
75	36	13.5	4.5	.02	.10	.00	.00
100	48	24	8	.06	.23	.00	.00
125	1 00	0 37.5	0 12.5	.11	.46	.00	.00
150	12	54	18	.20	.79	.00	.00
175	24	1 13.5	24.5	.31	1.25	.01	.00
200	36	36	32	.47	1.86	.02	.00
225	1 48	2 1.5	0 40.5	.66	2.65	.03	.00
250	2 00	30	50	.91	3.64	.05	.01
275	12	3 1.5	1 0.5	1.21	4.84	.08	.01
300	24	36	12	1.57	6.28	.12	.02
325	2 36	4 13.5	1 24.5	2.00	7.99	.18	.03
350	48	54	38	2.49	9.97	.26	.04
375	3 00	5 37.5	52.5	3.07	12.27	.36	.06
400	12	6 24	2 8	3.72	14.88	.50	.08
425	3 24	7 13.5	2 24.5	4.47	17.85	.68	.11
450	36	8 6	42	5.31	21.18	.90	.15
475	48	9 1.5	3 0.5	6.23	24.90	1.18	.20
500	4 00	10 0	20	7.26	29.02	1.52	.25
525	4 12	11 1.5	3 40.5	8.41	33.60	1.92	.33
550	24	12 6	4 2	9.66	38.62	2.44	.41
575	36	13 13.5	4 24.5	11.02	44.08	3.07	.51
600	48	14 24	4 48	12.50	50.06	3.78	.62
625	5 00	15 37.5	5 12.5	14.15	56.55	4.63	.77
650	12	16 54	5 38	15.90	63.55	5.63	.95
675	24	18 13.5	6 4	17.80	71.09	6.81	1.13
700	36	19 36	6 32	19.84	79.20	8.13	1.36

TABLE VI

TRANSITION SPIRAL

a = 0° 54′. 1° in 111.1 feet

l	*d*	*δ*	*θ*	*F*	*y*	*x* cor.	*t* cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
20	0 10.8	0 1.1	0 0.4	.00	.00	.00	.00
40	21.6	4.3	1.4	.00	.02	.00	.00
60	32.4	9.7	3.2	.01	.06	.00	.00
80	43.2	17.3	5.8	.03	.12	.00	.00
100	54.0	27.0	9.0	.06	.26	.00	.00
120	1 4.8	0 38.9	0 13.0	.11	.45	.00	.00
140	15.6	52.9	17.6	.18	.72	.00	.00
160	26.4	1 9.1	23.0	.27	1.07	.01	.00
180	37.2	27.5	29.2	.38	1.52	.01	.00
200	48.0	48.0	36.0	.52	2.09	.02	.00
220	1 58.8	2 10.7	0 43.6	.70	2.79	.03	.00
240	[illegible] 9.6	35.5	51.8	.90	3.62	.05	.01
260	20.4	3 2.5	1 00.8	1.15	4.60	.07	.01
280	31.2	31.7	10.6	1.43	5.74	.10	.02
300	42.0	4 3.0	21.0	1.77	7.08	.15	.03
320	2 52.8	4 36.5	1 32.2	2.14	8.58	.21	.03
340	3 3.6	5 12.1	44.0	2.57	10.28	.28	.05
360	14.4	49.9	56.6	3.05	12.20	.37	.07
380	25.2	6 29.9	2 10.0	3.59	14.35	.49	.08
400	36.0	7 12.0	24.0	4.19	16.73	.63	.11
420	3 46.8	7 56.3	2 38.8	4.84	19.36	.81	.13
440	57.6	8 42.7	54.2	5.57	22.26	1.01	.17
460	4 8.4	9 31.3	3 10.4	6.36	25.42	1.27	.21
480	19.2	10 22.1	27.3	7.23	28.86	1.57	.26
500	30.0	11 15.0	3 44.9	8.16	32.61	1.92	.32
520	4 40.8	12 10.1	4 3.3	9.18	36.66	2.34	.39
540	51.6	13 7.3	22.3	10.28	41.03	2.83	.47
560	5 2.4	14 6.7	42.1	11.47	45.74	3.39	.57
580	13.2	15 8.3	5 2.6	12.73	50.76	4.03	.67
600	24.0	16 12.0	23.8	14.09	56.15	4.77	.79
620	5 34.8	17 17.9	5 45.7	15.53	61.89	5.62	.94
640	45.6	18 25.9	6 8.3	17.07	68.00	6.59	1.10
660	56.4	19 36.1	31.6	18.71	74.51	7.68	1.27
680	6 7.2	20 48.5	55.7	20.46	81.39	8.91	1.47
700	18.0	22 3.0	7 20.5	22.31	88.65	10.29	1.70

TABLE VII

TRANSITION SPIRAL

a = 1° 0′. 1° in 100 feet

l	*d*	*δ*	*θ*	*F*	*y*	*x* cor.	*l* cor.
	°	° ′	° ′	Feet	Feet	Feet	Feet
10	.1	0 0.3	0 0.1	.000	.000	.000	.000
20	.2	1.2	0.4	.001	.002	.000	.000
30	.3	2.7	0.9	.002	.008	.000	.000
40	.4	4.8	1.6	.005	.019	.000	.000
50	.5	7.5	2.5	.009	.036	.000	.000
60	.6	0 10.8	0 3.6	.016	.063	.000	.000
70	.7	14.7	4.9	.025	.100	.000	.000
80	.8	19.2	6.4	.037	.149	.000	.000
90	.9	24.3	8.1	.053	.212	.000	.000
100	1.0	30	10	.073	.291	.001	.000
110	1.1	0 36.3	0 12.1	.097	.387	.001	.000
120	.2	43.2	14.4	.126	.503	.002	.000
130	.3	50.7	16.9	.160	.639	.003	.000
140	.4	58.8	19.6	.199	.798	.004	.000
150	.5	1 7.5	22.5	.245	.982	.006	.001
160	1.6	1 16.8	0 25.6	.298	1.191	.008	.001
170	.7	26.7	28.9	.357	1.429	.011	.002
180	.8	37.2	32.4	.424	1.696	.014	.002
190	.9	48.3	36.1	.499	1.995	.019	.003
200	2.0	2 00	40	.582	2.327	.024	.004
210	2.1	2 12.3	0 44.1	.673	2.690	.031	.005
220	.2	25.2	48.4	.774	3.097	.039	.006
230	.3	38.7	52.9	.885	3.538	.049	.008
240	.4	52.8	57.6	1.005	4.020	.061	.010
250	.5	3 7.5	1 2.5	1.136	4.544	.074	.012
260	2.6	3 22.8	1 7.6	1.278	5.111	.090	.015
270	.7	38.7	12.9	1.431	5.724	.109	.018
280	.8	55.2	18.4	1.596	6.383	.131	.022
290	.9	4 12.3	24.1	1.773	7.091	.156	.027
300	3.0	30	30	1.963	7.850	.185	.031
310	3.1	4 48.3	1 36.1	2.166	8.66	.218	.036
320	.2	5 7.2	42.4	2.382	9.53	.255	.043
330	.3	26.7	48.9	2.612	10.45	.298	.050
340	.4	46.8	55.6	2.857	11.42	.346	.058
350	.5	6 7.5	2 2.5	3.116	12.46	.400	.067
360	3.6	6 28.8	2 9.6	3.391	13.56	.460	.077
370	.7	50.7	16.9	3.681	14.72	.528	.088
380	.8	7 13.2	24.4	3.988	15.94	.603	.100
390	.9	36.3	32.1	4.311	17.23	.686	.114
400	4.0	8 00	40	4.651	18.59	.779	.130
410	4.1	8 24.3	2 48.1	5.01	20.02	.881	.147
420	.2	49.2	56.4	5.38	21.51	.994	.166
430	.3	9 14.7	3 4.9	5.78	23.08	1.118	.186
440	.4	40.8	13.6	6.19	24.73	1.254	.209
450	.5	10 7.5	22.5	6.62	26.45	1.403	.234
460	4.6	10 34.8	3 31.6	7.07	28.24	1.57	.26
470	.7	11 2.7	40.9	7.54	30.12	1.74	.29
480	.8	31.2	50.4	8.03	32.07	1.94	.32
490	.9	12 00.3	4 00.1	8.54	34.11	2.15	.36
500	5.0	30	10	9.07	36.23	2.37	.40
510	5.1	13 00.3	4 20.1	9.63	38.44	2.62	.44
520	.2	31.2	30.4	10.20	40.73	2.89	.48
530	.3	14 2.7	40.9	10.80	43.12	3.17	.53
540	.4	34.8	51.4	11.42	45.59	3.49	.58
550	.5	15 7.5	5 2.3	12.07	48.15	3.82	.64
560	5.6	15 40.8	5 13.4	12.74	50.83	4.18	.70
570	.7	16 14.7	24.7	13.43	53.56	4.56	.76
580	.8	49.2	36.2	14.14	56.40	4.98	.83
590	.9	17 24.3	47.8	14.89	59.34	5.42	.90
600	6.0	18 00	59.7	15.65	62.39	5.89	.98

TABLE VIII

TRANSITION SPIRAL

a = 1° 6′. 1° in 90.9 feet

l	*d*	*δ*	*θ*	*F*	*y*	*x* cor.	*t* cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
10	0 6.6	0 .3	0 0.1	.00	.00	.00	.00
20	13.2	1.3	0.4	.00	.00	.00	.00
30	19.8	3.0	1.0	.00	.01	.00	.00
40	26.4	5.3	1.8	.01	.02	.00	.00
50	33.0	8.2	2.7	.01	.04	.00	.00
60	0 39.6	0 11.9	0 4.0	.02	.07	.00	.00
70	46.2	16.1	5 4	.03	.11	.00	.00
80	52.8	21.1	7 0	.04	.16	.00	.00
90	59.4	26.7	8.9	.06	.23	.00	.00
100	1 6.0	33.0	11.0	.08	.32	.00	.00
110	1 12.6	0 39.9	0 13.3	.11	.43	.00	.00
120	19.2	47.5	15.8	.14	.55	.00	.00
130	25.8	55.8	18.6	.18	.70	.00	.00
140	32.4	1 4 7	21.6	.22	.88	.00	.00
150	39.0	14.2	24.7	.27	1.08	.01	.00
160	1 45.6	1 24.5	0 28.2	.33	1.31	.01	.00
170	52 2	35.4	31.8	.39	1 57	.01	.00
180	58.8	46.9	35.6	.47	1.87	.02	.00
190	2 5.4	59.1	39.7	.55	2.19	.02	.00
200	12.0	2 12.0	44.0	.64	2.56	.03	.00
210	2 18 6	2 25.5	0 48.5	.74	2.96	.04	.01
220	25.2	39 7	53.2	.85	3.41	.05	.01
230	31.8	54 6	58.2	.97	3.89	.06	.01
240	38.4	3 10.1	1 3.4	1.11	4.42	.07	.01
250	45.0	26.2	8.7	1.25	5.00	.09	.01
260	2 51.6	3 43.1	1 14.3	1.40	5.62	.11	.02
270	58.2	4 00.6	20.2	1.57	6.30	.13	.02
280	3 4.8	18.7	26.2	1.76	7.02	.16	.03
290	11.4	37.5	32.5	1.95	7.80	.19	.03
300	18.0	57.0	39.0	2.16	8.63	.22	.04
310	3 24.6	5 17.1	1 45 7	2.38	9.53	.26	.04
320	31.2	37.9	52.6	2.62	10.48	.31	.05
330	37.8	59.4	59.8	2.87	11.49	.36	.06
340	44.4	6 21.5	2 7.2	3.14	12.56	.42	.07
350	51.0	44.2	14.7	3.43	13.71	.49	.08
360	3 57.6	7 7.7	2 22.6	3.73	14.92	.56	.09
370	4 4.2	7 31.8	30.6	4.05	16.19	.64	.11
380	10.8	56.5	38.8	4.39	17.53	.73	.12
390	17.4	8 21.9	47.3	4.74	18.95	.83	.14
400	24.0	48.0	56.0	5.12	20.45	.94	.16
410	4 30.6	9 14.7	3 4.9	5.51	22.02	1.07	.18
420	37.2	42.1	14.0	5.92	23.66	1.20	.20
430	43.8	10 10.2	23.4	6.36	25.39	1.36	.23
440	50.4	38.9	32.9	6.81	27.20	1.52	.25
450	57.0	11 8.2	42.6	7.28	29.09	1.70	.28
460	5 3.6	11 38.3	3 52.7	7 78	31.06	1.90	.31
470	10.2	12 9.0	4 2.9	8.29	33.13	2.11	.35
480	16.8	40.3	13.3	8.83	35.28	2.35	.39
490	23.4	13 12.3	24.0	9.3[illegible]	37.52	2.60	.43
500	30.0	45.0	34.9	9.98	39.86	2.87	.48
510	5 36.6	14 18.3	4 26.0	10.59	42.28	3.17	.53
520	43.2	52.3	37.3	11.22	44.80	3.50	.58
530	49.8	15 27.0	5 8.8	11.88	47.43	3.84	.64
540	56.4	16 2.3	20.6	12.56	50.15	4.22	.70
550	6 3.0	38.2	32.5	13.28	52.97	4.62	.77
560	6 9.6	17 14.9	5 44.8	14.01	55.91	5.06	.85
570	16.2	52.2	57.1	14.77	58.92	5.52	.92
580	22.8	18 30.1	6 9.7	15.55	62.04	6.03	1.00
590	29.4	19 8.7	22.6	16.38	65.27	6.56	1.09
600	36.0	48.0	35.6	17.21	68.63	7.13	1.19

TABLE IX

TRANSITION SPIRAL

a = 1° 15′. 1° in 80 feet

l	d	δ	θ	F	y	x cor.	t cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
10	0 7.5	0 0.5	0 0	.00	.00	.0	.0
20	15	1.5	0.5	.00	.00	.0	.0
30	22.5	3.5	1	.00	.01	.0	.0
40	30	6	2	.00	.02	.0	.0
50	37.5	9.5	3	.01	.04	.0	.0
60	0 45	0 13.5	0 4.5	.02	.08	.0	.0
70	52.5	18.5	6	.03	.12	.0	.0
80	1 0	24	8	.05	.19	.0	.0
90	7.5	30.5	10	.07	.26	.0	.0
100	15	37.5	12.5	.09	.36	.0	.0
110	1 22.5	0 45.5	0 15	.12	.48	.0	.0
120	30	54	18	.16	.63	.0	.0
130	37.5	1 3.5	21	.20	.80	.0	.0
140	45	13.5	24.5	.25	1.00	.0	.0
150	52.5	24.5	28	.31	1.23	.0	.0
160	2 0	1 36	0 32	.37	1.49	.0	.0
170	7.5	48.5	36	.45	1.77	.0	.0
180	15	2 1.5	40.5	.53	2.12	.0	.0
190	22.5	15.5	45	.62	2.50	.0	.0
200	30	30	50	.73	2.90	.0	.0
210	2 37.5	2 45.5	0 55	.84	3.36	.0	.0
220	45	3 1.5	1 00.5	.97	3.87	.0	.0
230	52.5	18.5	6	1.10	4.42	.0	.0
240	3 0	36	12	1.25	5.02	.0	.0
250	7.5	54.5	18	1.42	5.67	.1	.0
260	3 15	4 13.5	1 24.5	1.59	6.38	.1	.0
270	22.5	33.5	31	1.79	7.15	.2	.0
280	30	54	38	1.99	7.98	.2	.0
290	37.5	5 15.5	45	2.21	8.86	.2	.0
300	45	37.5	52.5	2.45	9.81	.3	.0
310	3 52.5	6 .5	2 0	2.70	10.74	.3	.0
320	4 0	24	8	2.98	11.91	.4	.0
330	7.5	48.5	16	3.26	13.06	.4	.0
340	15	7 13.5	24.5	3.57	14.28	.5	.0
350	22.5	39.5	33	3.89	15.57	.6	.0
360	4 30	8 6	2 42	4.23	16.95	.7	.1
370	37.5	33.5	51	4.59	18.40	.8	.1
380	45	9 1.5	3 00.5	4.97	19.92	.9	.2
390	52.5	30.5	10	5.38	21.54	1.0	.2
400	5 00	10 00	20	5.80	23.23	1.2	.2
410	5 7.5	10 30.5	3 30	6.26	25.00	1.4	.2
420	15	11 1.5	40.5	6.72	26.86	1.6	.3
430	22.5	33.5	51	7.22	28.82	1.7	.3
440	30	12 06	4 02	7.74	30.87	2.0	.3
450	37.5	39.5	13	8.28	33.02	2.2	.4
460	5 45	13 13.5	4 24.5	8.84	35.25	2.4	.4
470	52.5	48.5	36	9.41	37.59	2.7	.5
480	6 00	14 24	48	10.03	40.02	3.0	.5
490	7.5	15 00.5	5 00	10.67	42.56	3.4	.6
500	15	37.5	12.5	11.33	45.20	3.7	.6
510	6 22.5	16 15.5	5 25	12.03	47.95	4.1	.7
520	30	54	38	12.74	50.79	4.5	.8
530	37.5	17 33.5	51	13.48	53.76	5.0	.8
540	45	18 13.5	6 4	14.26	56.84	5.4	.9
550	52.5	54.5	18	15.07	60.02	6.0	1.0
560	7 0	19 36	6 32	15.90	63.34	6.5	1.1
570	7.5	20 18.5	46	16.76	66.72	7.1	1.2
580	15	21 1.5	7 00	17.65	70.26	7.8	1.3
590	22.5	45.5	14.5	18.57	73.90	8.4	1.4
600	30	22 30	29	19.52	77.68	9.2	1.5

TABLE X

TRANSITION SPIRAL

a = 1° 40′. 1° in 60 feet

l	*d*	*δ*	*θ*	*F*	*y*	*x* cor.	*t* cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
10	0 10	0 0.5	0 0	.00	.00	.0	.0
20	20	2	0.5	.00	.00	.0	.0
30	30	4.5	1.5	.00	.00	.0	.0
40	40	8	3	.00	.03	.0	.0
50	50	12.5	4	.00	.06	.0	.0
60	1 00	0 18	0 6	.03	.10	.0	.0
70	10	24.5	8	.04	.17	.0	.0
80	20	32	10.5	.06	.25	.0	.0
90	30	40.5	13 5	.09	.35	.0	.0
100	40	50	16.5	.12	.48	.0	.0
110	1 50	1 00.5	0 20	.16	.64	.0	.0
120	2 00	12	24	.21	.84	.0	.0
130	10	24.5	28	.26	1.06	.0	.0
140	20	38	32.5	.33	1.33	.0	.0
150	30	52.5	37.5	.41	1.63	.0	.0
160	2 40	2 8	0 42.5	.50	1.98	.0	.0
170	50	24.5	48	.59	2.38	.0	.0
180	3 00	42	54	.70	2.82	.0	.0
190	10	3 00.5	1 00	.83	3.32	.0	.0
200	20	20	6.5	.97	3.88	.0	.0
210	3 30	3 40.5	1 13.5	1.12	4.48	.1	.0
220	40	4 2	20.5	1.29	5.15	.1	.0
230	50	24.5	28	1.47	5.90	.1	.0
240	4 00	48	36	1.67	6.69	.2	.0
250	10	5 12.5	44	1.89	7.58	.2	.0
260	4 20	5 38	1 52.5	2.13	8.52	.2	.0
270	30	6 4.5	2 1.5	2.38	9.54	.3	.0
280	40	32	10.5	2.65	10.64	.4	.0
290	50	7 00.5	20	2.94	11.82	.4	.0
300	5 00	30	30	3.26	13.07	.5	.0
310	5 10	8 00.5	2 40	3.60	14.43	.6	.1
320	20	32	50.5	3.96	15.87	.7	.1
330	30	9 04.5	3 1.5	4.34	17.40	.8	.1
340	40	38	12.5	4.75	19.02	.9	.2
350	50	10 12.5	24	5.18	20.74	1.1	.2
360	6 00	10 48	3 36	5.64	22.56	1.3	.2
370	10	11 24.5	48	6.12	24.50	1.4	.2
380	20	12 2	4 00.5	6.63	26.53	1.7	.3
390	30	40.5	13.5	7.16	28.67	1.9	.3
400	40	13 20	26.5	7.73	30.92	2.2	.4
410	6 50	14 00.5	4 40	8.34	33.27	2.4	.4
420	7 00	42	54	8.96	35.73	2.8	.5
430	10	15 24.5	5 8	9.61	38.32	3.1	.5
440	20	16 8	22.5	10.30	41.07	3.5	.6
450	30	52.5	37.5	11.01	43.90	3.9	.6
460	7 40	17 38	5 52	11.75	46.86	4.3	.7
470	50	18 24.5	6 8	12.50	49.94	4.8	.8
480	8 00	19 12	24	13.35	53.16	5.4	.9
490	10	20 00.5	40	14.19	56.52	5.9	1.0
500	20	50	56	15.07	60.01	6.6	1.1
510	8 30	21 40.5	7 13	16.00	63.64	7.2	1.2
520	40	22 32	30	16.94	67.36	8.0	1.3
530	50	23 24.5	47.5	17.93	71.25	8.8	1.5
540	9 00	24 18	8 5	18.95	75.31	9.6	1.6
550	10	25 12.5	23	20.03	79.53	10.5	1.8
560	9 20	26 8	8 42	21.13	83.88	11.5	1.9
570	30	27 4.5	9 00.5	22.26	88.31	12.6	2.1
580	40	28 2	19.5	23.42	92.92	13.7	2.3
590	50	29 00.5	39	24.67	97.70	14.9	2.5
600	10 00	30 00	59	25.91	102.66	16.2	2.7

TABLE XI
TRANSITION SPIRAL
a = 2° 0′. 1° in 60 feet

l	*d*	*δ*	*θ*	*F*	*y*	*x* cor.	*t* cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
10	0 12	0 0.5	0 0	.00	.00	.0	.0
20	24	2.5	1	.00	.00	.0	.0
30	36	5.5	2	.00	.02	.0	.0
40	48	9.5	3	.01	.04	.0	.0
50	1 00	15	5	.02	.07	.0	.0
60	1 12	0 21.5	0 7	.03	.13	.0	.0
70	24	29.5	10	.05	.20	.0	.0
80	36	38.5	13	.07	.30	.0	.0
90	48	48.5	16	.10	.42	.0	.0
100	2 00	1 00	20	.15	.58	.0	.0
110	2 12	1 12.5	0 24	.19	.77	.0	.0
120	24	26.5	29	.25	1.00	.0	.0
130	36	41.5	34	.32	1.28	.0	.0
140	48	57.5	39	.40	1.60	.0	.0
150	3 00	2 15	45	.49	1.96	.0	.0
160	3 12	2 33.5	0 51	.59	2.38	.0	.0
170	24	53.5	58	.71	2.86	.0	.0
180	36	3 14.5	1 5	.85	3.39	.1	.0
190	48	36.5	12	1.00	3.99	.1	.0
200	4 00	4 00	20	1.16	4.65	.1	.0
210	4 12	4 24.5	1 28	1.35	5.38	.1	.0
220	24	50.5	37	1.54	6.19	.2	.0
230	36	5 17.5	46	1.76	7.07	.2	.0
240	48	45.5	55	2.00	8.04	.2	.0
250	5 00	6 15	2 5	2.27	9.09	.3	.0
260	5 12	6 45.5	2 15	2.55	10.22	.4	.0
270	24	7 17.5	26	2.85	11.45	.4	.0
280	36	50.5	37	3.18	12.75	.5	.0
290	48	8 24.5	48	3.54	14.18	.6	.1
300	6 00	9 00	3 00	3.91	15.68	.7	.1
310	6 12	9 36.5	3 12	4.32	17.31	.9	.1
320	24	10 14.5	25	4.75	19.03	1.0	.2
330	36	53.5	38	5.21	20.87	1.2	.2
340	48	11 33.5	51	5.70	22.81	1.4	.2
350	7 00	12 15	4 5	6.22	24.87	1.6	.3
360	7 12	12 57.5	4 19	6.77	27.05	1.8	.3
370	24	13 41.5	34	7.34	29.35	2.1	.3
380	36	14 26.5	49	7.95	31.79	2.4	.4
390	48	15 12.5	5 4	8.60	34.35	2.7	.4
400	8 00	16 00	20	9.28	37.04	3.1	.5
410	8 12	16 48.5	5 36	10.00	39.85	3.5	.6
420	24	17 38.5	53	10.73	42.79	4.0	.7
430	36	18 29.5	6 10	11.53	45.88	4.4	.7
440	48	19 21.5	27	12.34	49.14	5.0	.8
450	9 00	20 15	45	13.20	52.55	5.6	.9
460	9 12	21 9.5	7 3	14.09	56.05	6.3	1.0
470	24	22 5.5	21	15.02	59.73	6.9	1.2
480	36	23 2.5	40	15.99	63.55	7.7	1.3
490	48	24 0.5	8 00	17.00	67.55	8.5	1.4
500	10 00	25 00	19	18.05	71.72	9.4	1.6
510	10 12	26 0.5	8 39	19.15	76.00	10.4	1.7
520	24	27 2.5	9 00	20.27	80.04	11.4	1.9
530	36	28 5.5	21	21.45	85.08	12.6	2.1
540	48	29 9.5	42	22.68	89.88	13.8	2.3
550	11 00	30 15	10 3.5	23.96	94.85	15.1	2.5
560	11 12	31 21.5	10 26	25.27	99.97	16.5	2.8
570	24	32 29.5	48	26.62	105.19	18.0	3.0
580	36	33 38.5	11 10.5	28.01	110.62	19.6	3.3
590	48	34 48.5	34	29.48	116.27	21.3	3.6
600	12 00	36 00	58	30.97	122.13	23.2	3.9

TABLE XII

TRANSITION SPIRAL

a = 2° 30′. 1° in 40 feet

l	d	δ	θ	F	y	x cor.	t cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
10	0 15	0 1	0 0	.00	.00	.0	.0
20	30	3	1	.00	.00	.0	.0
30	45	7	2	.00	.02	.0	.0
40	1 00	12	4	.01	.05	.0	.0
50	15	19	6	.02	.09	.0	.0
60	1 30	0 27	0 9	.04	.16	.0	.0
70	45	37	12	.06	.25	.0	.0
80	2 00	48	16	.09	.37	.0	.0
90	15	1 1	20	.13	.53	.0	.0
100	30	15	25	.18	.73	.0	.0
110	2 45	1 31	0 30	.24	.97	.0	.0
120	3 00	48	36	.31	1.25	.0	.0
130	15	2 7	42	.40	1.60	.0	.0
140	30	27	49	.50	2.00	.0	.0
150	45	49	56	.61	2.45	.0	.0
160	4 00	3 12	1 4	.74	2.97	.0	.0
170	15	37	12	.89	3.57	.0	.0
180	30	4 3	21	1.06	4.24	.1	.0
190	45	31	30	1.25	4.99	.1	.0
200	5 00	5 00	40	1.45	5.81	.2	.0
210	5 15	5 31	1 50	1.68	6.72	.2	.0
220	30	6 3	2 1	1.93	7.74	.2	.0
230	45	37	12	2.20	8.85	.3	.0
240	6 00	7 12	24	2.51	10.05	.4	.0
250	15	49	36	2.84	11.37	.5	.1
260	6 30	8 27	2 49	3.19	12.77	.6	.1
270	45	9 7	3 2	3.57	14.29	.7	.1
280	7 00	48	16	3.98	15.94	.8	.1
290	15	10 31	30	4.42	17.70	1.0	.2
300	30	11 15	45	4.89	19.59	1.2	.2
310	7 45	12 1	4 00	5.40	21.61	1.4	.2
320	8 00	48	16	5.94	23.76	1.6	.3
330	15	13 37	32	6.51	26.05	1.9	.3
340	30	14 27	49	7.12	28.46	2.2	.4
350	45	15 19	5 6	7.77	31.03	2.5	.4
360	9 00	16 12	5 24	8.46	33.74	2.9	.5
370	15	17 7	42	9.18	36.62	3.3	.5
380	30	18 3	6 1	9.95	39.64	3.7	.6
390	45	19 1	20	10.75	42.82	4.3	.7
400	10 00	20 00	40	11.60	46.16	4.9	.8
410	10 15	21 1	7 00	12.47	49.65	5.5	.9
420	30	22 3	21	13.39	53.28	6.2	1.0
430	45	23 7	42	14.38	57.10	6.9	1.2
440	11 00	24 12	8 4	15.39	61.12	7.8	1.3
450	15	25 19	26	16.45	65.32	8.7	1.5

TABLE XIII

TRANSITION SPIRAL

$a = 3° 20'$. 1° in 30 feet

l	d	δ	θ	F	y	x cor.	t cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
10	0 20	0 1	0 0	.00	.00	.0	.0
20	40	4	1	.00	.01	.0	.0
30	1 00	9	3	.01	.03	.0	.0
40	20	16	5	.02	.06	.0	.0
50	40	25	8	.03	.12	.0	.0
60	2 00	0 36	0 12	.05	.21	.0	.0
70	20	49	16	.08	.33	.0	.0
80	40	1 4	21	.12	.50	.0	.0
90	3 00	21	27	.18	.71	.0	.0
100	20	40	33	.24	.97	.0	.0
110	3 40	2 1	0 40	.32	1.29	.0	.0
120	4 00	24	48	.42	1.68	.0	.0
130	20	49	56	.53	2.13	.0	.0
140	40	3 16	1 5	.67	2.66	.0	.0
150	5 00	45	15	.82	3.27	.1	.0
160	5 20	4 16	1 25	.99	3.97	[illegible]	.0
170	40	49	36	1.19	4.76	.1	.0
180	6 00	5 24	48	1.41	5.65	.2	.0
190	20	6 1	2 00	1.66	6.65	.2	.0
200	40	40	13	1.94	7.75	.3	.0
210	7 00	7 21	2 27	2.24	8.97	.3	.1
220	20	8 4	41	2.58	10.31	.4	.1
230	40	49	56	2.95	11.77	.5	.1
240	8 00	9 36	3 12	3.35	13.38	.7	.1
250	20	10 25	28	3.78	15.11	.8	.1
260	8 40	11 16	3 45	4.25	17.00	1.0	.2
270	9 00	12 9	4 3	4.76	19.02	1.2	.2
280	20	13 4	21	5.31	21.20	1.4	.2
290	40	14 1	40	5.90	23.55	1.7	.3
300	10 00	15 00	5 00	6.53	26.05	2.0	.3
310	10 20	16 1	5 20	7.20	28.72	2.4	.4
320	40	17 4	41	7.92	31.57	2.8	.5
330	11 00	18 9	6 3	8.69	34.59	3.3	.5
340	20	19 16	25	9.49	37.80	3.8	.6
350	40	20 25	48	10.35	41.19	4.4	.7
360	12 00	21 36	7 11	11.25	44.78	5.1	.8
370	20	22 49	36	12.21	48.56	5.8	1.0
380	40	24 4	8 00	13.22	52.53	6.6	1.1
390	13 00	25 21	26	14.28	56.71	7.6	1.3
400	20	26 40	52	15.39	61.10	8.6	1.4
410	13 40	28 1	9 19	16.56	65.69	9.7	1.6
420	14 00	29 24	47	17.79	70.49	10.9	1.8
430	20	30 49	10 15	19.07	75.51	12.3	2.1
440	40	32 16	43	20.41	80.74	13.7	2.3
450	15 00	33 45	11 13	21.81	86.19	15.4	2.6

TABLE XIV
TRANSITION SPIRAL
a = 5° 0′. 1° in 20 feet

l	*d*	*δ*	*θ*	*F*	*y*	*x* cor.	*t* cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
10	0 30	0 1	0 0	.00	.00	.0	.0
20	1 00	6	2	.00	.01	.0	.0
30	30	13	4	.01	.04	.0	.0
40	2 00	24	8	.02	.09	.0	.0
50	30	37	12	.05	.18	.0	.0
60	3 00	0 54	0 18	.08	.31	.0	.0
70	30	1 13	24	.12	.50	.0	.0
80	4 00	36	32	.19	.74	.0	.0
90	30	2 1	40	.26	1.06	.0	.0
100	5 00	30	50	.36	1.45	.0	0
110	[illegible] 30	3 1	1 00	.48	1.94	.0	0
120	6 00	36	12	.62	2.51	.0	.0
130	30	4 13	24	.79	3.20	.0	.0
140	7 00	54	38	.99	3 99	.1	.0
150	30	5 37	52	1.22	4.90	.1	.0
160	8 00	6 24	2 8	1.48	5.96	.2	.0
170	30	7 13	24	1.78	7.15	.3	.0
180	9 00	8 6	42	2.11	8.49	.4	.0
190	30	9 1	3 00	2.49	9.98	.5	.0
200	10 00	10 0	20	2.90	11.62	.6	.1
210	10 30	11 1	3 40	3.36	13.45	.8	.1
220	11 00	12 6	4 2	3.86	15.44	1.0	.2
230	30	13 13	24	4.41	17.63	1.2	.2
240	12 00	14 24	48	5.01	20.01	1.5	.3
250	30	15 37	5 12	5.66	22.60	1.8	.3
260	13 00	16 54	5 38	6.37	25.38	2.2	.4
270	30	18 13	6 4	7.12	28.39	2.7	.5
280	14 00	19 36	32	7.94	31.62	3.3	.6
290	30	21 2	7 00	8.82	35.10	3.9	.7
300	15 00	22 30	29	9.76	38 83	4.6	.8
310	15 30	24 2	8 00	10.76	42.73	5.4	.9
320	16 00	25 36	31	11.82	46.92	6.3	1.1
330	30	27 13	9 04	12.95	51.36	7.4	1.2
340	17 00	28 54	37	14.15	56.05	8.6	1.4
350	30	30 37	10 11	15.43	61.09	9.9	1.7
360	18 00	32 24	10 46	16.75	66.31	11.3	1.9
370	30	34 14	11.19	18.16	71.63	13.0	2.2
380	19 00	36 6	12 00	19 65	77.35	14.8	2.5
390	30	38 2	38	21.21	83.41	16.8	2.8
400	20 00	40 0	13 17	22.87	89.83	19.0	3.2

TABLE XV
TRANSITION SPIRAL
a = 10° 0′. 1° in 10 feet

l	*d*	*δ*	*θ*	*F*	*y*	*x* cor.	*t* cor.
	° ′	° ′	° ′	Feet	Feet	Feet	Feet
10	1 00	0 3	0 1	.00	.00	.0	.0
20	2	12	4	.01	.02	.0	.0
30	3	27	9	.02	.08	.0	.0
40	4	48	16	.05	.19	.0	.0
50	5	1 15	25	.09	.36	.0	.0
60	6 00	1 48	0 36	.16	.63	.0	.0
70	7	2 27	49	.25	1.00	.0	.0
80	8	3 12	1 4	.37	1.49	.0	.0
90	9	4 3	21	.53	2.12	.0	.0
100	10	5 0	40	.73	2.91	.1	.0
110	11 00	6 3	2 1	.97	3.87	.1	.0
120	12	7 12	24	1.26	5.02	.2	.0
130	13	8 27	49	1.60	6.38	.3	.0
140	14	9 48	3 16	1.99	7.97	.4	.1
150	15	11 15	45	2.45	9.79	.6	.1
160	16 00	12 48	4 16	2.97	11.87	.8	.1
170	17	14 27	49	3.56	14.23	1.1	.2
180	18	16 12	5 24	4.23	16.87	1.4	.2
190	19	18 3	6 1	4.97	19.81	1.9	.3
200	20	20 0	39	5.79	23.07	2.4	.4
210	21 00	22 3	7 20	6.70	26.65	3.1	.5
220	22	24 12	8 3	7.69	30.58	3.9	.6
230	23	26 27	48	8.78	34.86	4.8	.8
240	24	28 48	9 35	9.96	39.49	6.0	1.0
250	25	31 15	10 23	11.24	44.49	7.3	1.2
260	26 00	33 48	11 14	12.61	49.67	8.9	1.5
270	27	36 27	12 7	14.07	55.30	10.8	1.8
280	28	39 12	13 1	15.67	61.40	12.9	2.1
290	29	42 3	57	17.39	67.97	15.3	2.6
300	30	45 0	14 55	19.23	75.07	18.1	3.1

EARTHWORK

EARTHWORK SURVEYS

CUTS AND FILLS

1. Necessity for Cuts and Fills.—Economical railroad operation demands that the road shall be level or very nearly so. The natural surface of the ground is usually rough, and, in order to obtain a practically level road, it is necessary to equalize the irregularities of the surface by means of *fills* and *cuts*.

2. A **fill**, Fig. 1, is an embankment that supports the roadbed above the natural surface.

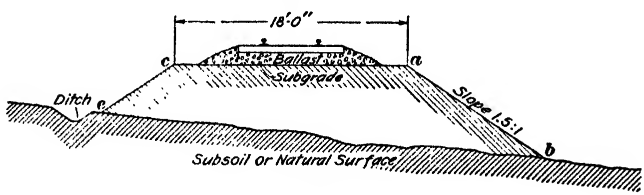


FIG. 1

3. A **cut**, Fig. 2, is an excavation that permits the roadbed to be placed below the natural surface. This definition is not intended to include tunnels.

4. The **subgrade**, Figs. 1 and 2, is the surface on which the ballast rests. In a fill, the subgrade is the top surface (ac, Fig. 1) of the embankment; in a cut, it is the lower surface ($a'c'$, Fig. 2) of the soil that is removed.

5. The **subsoil** is either the natural soil on which an embankment rests or the natural soil under the subgrade of an excavation. See Figs. 1 and 2.

6. The term **roadbed** is usually applied to the subgrade and ballast; it includes the ditches in a cut. The phrase "width of roadbed," when applied to a fill, means the total width ($a\,c$, Fig. 1) of the subgrade; when applied to a cut,

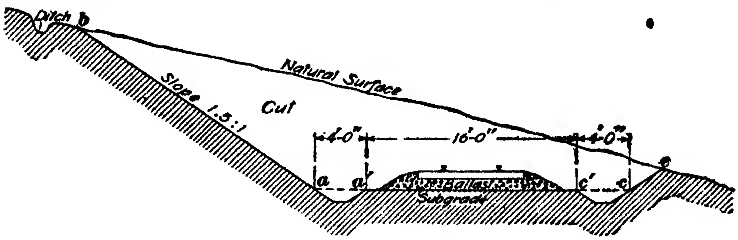


FIG. 2

it means the width ($a\,c$, Fig. 2) of the subgrade plus the width of both side ditches.

7. Grade is a term applied to the longitudinal slope or inclination of the track. The term is also used, in contradistinction to the term *subgrade*, to denote the upper surface of the ties or the base of the rails. The expression "level grade" is often used in the sense of level track, or level road.

8. Side Slope.—By the **side slope,** or simply the **slope,** of a cut or fill is meant the inclination of the sides ($a\,b$ and $e\,c$, Figs. 1 and 2) of the cut or fill to the vertical. A side slope is usually indicated by stating the rate at which the side of the cut or fill diverges from the vertical. This rate is called the **rate of slope, or slope ratio.** Thus, a slope of 2 to 1, or, as usually written, 2 : 1, is one in which the side diverges from the vertical at the rate of 2 units of length measured horizontally in every unit of length measured vertically. In Fig. 3, which shows different rates of slope, the ratio 2 : 1 marked on $A\,F$ indicates that, in the vertical distance $A\,O = 1$, the horizontal distance $O\,F$ by which the line $A\,F$ diverges from the vertical is 2. Likewise, the ratio 4 : 1 on $A\,G$ indicates that, in a vertical distance equal

to 1, the line AG diverges or deviates from the vertical by a distance OG equal to 4. It will be observed that the slope, or rate of slope, of a line is the tangent of the angle that the line makes with the vertical. Thus, in the case of AC, Fig. 3,

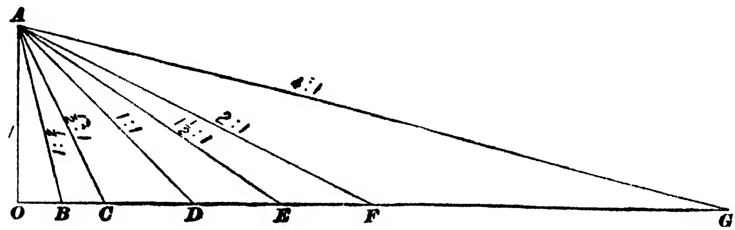


FIG. 3

the slope $\frac{1}{2}:1$, is equal to $OC \div OA = \tan OAC$. In what follows, the rate of slope will be denoted by s.

9. Slope Ratio in Cuts.—The very hardest and firmest rock may sometimes be safely cut out so as to leave a vertical face of wall; but it should be observed that rock which appears very hard and firm when first excavated often contains seams that will be opened by the action of frost, and may cause large pieces to break out. On this account, care should be taken to dislodge all loose masses of rock. This will practically mean that the surface will have an average slope of about $\frac{1}{4}:1$. As the soil becomes less firm, the slope must be flattened, until for a soil of firm earth or gravel a slope of 1 : 1 may be permissible for cuts, although a slope of $1\frac{1}{2}:1$ is commonly adopted, especially if the soil is soft and liable to wash. As before stated, a very soft and treacherous soil may require that the slope ratio be cut down even as flat as 4 : 1.

10. Slope Ratio in Fills.—A fill is usually made from the material excavated in an adjoining cut; but if it should happen that the quality of the soil is such that it is liable to slide, it may prove to be an economy to reject such soil by "wasting" it, even though it may be necessary to "borrow" a better grade of soil from some place in the neighborhood of the fill. An earthwork fill is generally made with a slope

ratio of $1\frac{1}{2} : 1$. This may be considered standard practice. When a fill is made from the material taken from a rock cut, it may be possible to make a stable embankment with a slope ratio of 1 : 1. On side-hill work, where a slope ratio of $1\frac{1}{2} : 1$ or even 1 : 1 might require a very long slope, it may often be advisable to make a rough dry wall of the stones from a rock cut, which will have a slope ratio of $\frac{3}{4} : 1$, or may even be steeper.

11. Width of Excavations and Embankments. The width required for a standard-gauge single-track roadbed may be estimated as follows (see Figs. 1 and 2): The tie will be between 8 and 9 feet long, usually 8 feet 6 inches. At the ends of the ties, the ballast will slope down to subgrade. The extra width required for this varies with the kind of ballast used and with other conditions that will be explained more fully under the subject of ballast, but it will be about 1 or 2 feet at each end of the tie. Usually, the embankment is widened for about 2 feet beyond the ballast on each side. The absolute minimum for the width of subgrade for a fill is, therefore, $8\frac{1}{2}$ feet $+ 2 \times (1 + 2)$ feet, or about $14\frac{1}{2}$ feet. This width would only be used for light-traffic, cheaply-constructed roads; 16 to 18 feet is far more common, while 20 feet and even more is frequently used, as the danger of accident due to a washing out of the embankment is materially reduced by widening the roadbed.

In cuts, the proper width for two ditches should be added. Unless the soil is especially firm, the ditches should have a side slope of 1.5 : 1. If the ditch is 12 inches wide at the base and 12 inches deep, with side slopes of 1.5 : 1, each ditch will require a total width of 4 feet. This will add 8 feet to the width of the cut at the elevation of subgrade. The usual distance between track centers for double track is 13 feet. Therefore, whatever rate of side slopes and width of ditches is required for single-track work, the width for double-track work must be 13 feet greater. When excavation is made through rock, the side slopes of the ditches may properly be made much steeper; the danger of scouring

during heavy rain storms being eliminated, the total required width may be very materially reduced from the figures just given. The heavy expense of excavating through solid rock requires that such economy shall be used if possible.

12. Ditching.—The great enemy of track maintenance is water, because it not only scours away the subsoil and ballast, but also freezes in winter, heaves the soil, and produces a rough track, which becomes a soft track when it thaws out. It is, therefore, of the utmost importance that adequate ditches should be provided to carry away quickly from the roadbed all rain water that may fall on or near it. Ditches should be constructed on both sides of the track through cuts. The bottom of the ditch should be enough lower than the subgrade to drain the water from it. A ditch should also be constructed at the top of a cut, so as to catch all the water that may come down the natural slope above the cut and prevent it from washing down the side of the cut; this ditch is shown at *b*, Fig. 2. All such ditches should lead off to some water course, if possible, or at least to some point where the outfall may not cause any scour. If the soil is very soft and the amount of water that will go through any one ditch is very large, it may cause such a scour that paving the ditch becomes economical.

FIELD WORK

13. The first step in the work of construction is to clear off all growth of timber within the limits of the right of way. The engineer with his party passes over the line, making offsets to the right and to the left, and blazing the trees that stand on, or just within, the limits of the company's property. The blazed spot is marked with a letter C, as a guide to the contractor. The valuable timber, when felled, should be piled near the boundary lines, to be saved as the property of the company; the brushwood should be burned. Where a deep cut is to be made, the stumps are left to be removed as the earth is excavated. In very shallow cuts and fills, the

contractor will generally prefer to tear up the trees by the roots at once, rather than to grub out the stumps after clearing. Where the embankments will be over 3 feet high, grubbing is not necessary; but the trees require to be *low-chopped*, leaving no stumps above the roots. The engineer should indicate to the contractor the localities where each process is suitable.

While the clearing is in progress, the engineer should run a line of test levels touching on all the benches to verify their elevations; he may also rerun the center line, replacing any stakes that have disappeared, and setting additional stakes wherever the inclination of the natural surface along the center line changes abruptly. If any changes in the alinement have been ordered, these should be made at the same time.

14. The Grade Profile.—The engineer is furnished with a profile of the line on which the established grade is indicated. This established grade on the profile consists of a series of straight lines, the elevations of the ends of which should be clearly indicated. These elevations are the elevations of the subgrade *a c*, Figs. 1 and 2.

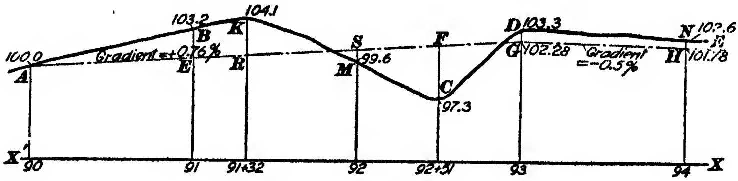


FIG. 4

A short portion of a profile is shown in Fig. 4. The horizontal line XX' represents any horizontal plane, and the broken line AGH shows the position of the established grade. The station numbers are written along the line XX', and the elevations of the corresponding points of the established grade are written along the grade line. Thus, in Fig. 4, the elevation of subgrade at Sta. 90, or A, is 100 feet; at Sta. 93, or G, it is 102.28 feet; and at Sta. 94, or H, it is 101.78 feet.

The **gradient** of the established grade is the number of feet by which the elevation of the established grade increases or decreases in a distance of one station. If the grade is ascending, the gradient is considered positive; if descending, it is negative. Use is made of the % sign in order to indicate the gradient. Thus, the gradient of a grade that rises 1 foot per station is + 1%; if the grade falls $2\frac{1}{3}$ feet in every 100 feet, its gradient is − 2.33%; etc. When the gradients are known and also the elevation of any one point of the established grade, the elevations of other points on this grade are easily computed, as will be presently explained.

15. The Depth of Center Stake.—Having set stakes on the center line at every full station and also at all intermediate points at which the inclination of the natural surface of the ground changes abruptly, the engineer should determine, by leveling, the elevation of the natural surface of the ground at each stake, and construct a profile $ABCDE$, Fig. 4, as explained in *Leveling*. The difference between the elevation of the natural surface at any stake and the elevation of the established grade at that stake is called the **depth of the stake.** The depth should be clearly marked on each stake, preceded by the letter C or F to indicate a cut or a fill.

Thus, if $ABCDE$ is the natural surface in Fig. 4, stakes will be set at the full stations A, B, M, D, and N, and also at the points K and C at which the slope of the profile of the natural surface changes. If the gradient of AG is + .76% and the elevation of A is 100.00 feet, the elevation of the point E will evidently be $100.00 + .76 \times 1 = 100.76$ feet, or (closely enough) 100.8 feet. If the elevation of the natural surface at B is 103.2, the depth of stake at B will be $103.2 - 100.8 = 2.4$ feet. This stake will therefore be marked C 2.4. The elevation of F will be $100.00 + .76 \times 2.51 = 101.9$ feet. If the elevation of C is 97.3 feet, the depth of the stake at C will be $101.9 - 97.3 = 4.6$ feet. This stake will be marked F 4.6.

Two additional columns, headed "Subgrade" and "Center Depth," must be added to the left-hand page of the level

book. In the column headed "Subgrade," the elevation of the established grade at each stake is entered; and in the column headed "Center Depth," the cut or fill is written. The gradient is usually written along the first column, as indicated in the following example. In this example, the columns of rod readings from which the elevations of points on the natural surface are obtained are omitted. The student is already familiar with the method of finding these elevations from the rod readings.

EXAMPLE.—Stakes are set at the stations indicated in the first column of the accompanying field notes. The gradient is + .76% from Sta. 90 to Sta. 93, and − .50% beyond Sta. 93. The elevation of the established grade at Sta. 90 is 100.00 feet; the elevation of the natural surface at each stake is given in the third column. To find the center depth at each stake. (See Fig. 4.)

Station	Subgrade	Elevation	Depth of Center Stake
94	101.8	102.6	C .8
93	102.28	103.3	C 1.0
92 + 51	101.9	97.3	F 4.6
92	101.5	99.6	F .9
91 + 32	101.0	104.1	C 3.1
91	100.8	103.2	C 2.4
90	100.00	100.0	0.0

SOLUTION.—The elevations of the subgrade at the station stakes are determined as follows:

STATION	ELEVATION
91	$100.00 + 1.00 \times .76 = 100.8$
91 + 32	$100.00 + 1.32 \times .76 = 101.0$
92	$100.00 + 2.00 \times .76 = 101.5$
92 + 51	$100.00 + 2.51 \times .76 = 101.9$
93	$100.00 + 3.00 \times .76 = 102.28$
94	$102.28 + 1.00 \times - .50 = 101.8$

The center depth is the difference between the corresponding numbers in the second and third columns. This is a fill if the subgrade is higher than the natural surface; otherwise, it is a cut.

EXAMPLES FOR PRACTICE

In the following examples, the elevations of the natural surface at the stakes indicated are given. It is required to find the depth at each center stake.

1. Sta. 3, 65.0; Sta. 4, 67.1; Sta. 5, 70.8; Sta. 5 + 20, 71.3; Sta. 5 + 80, 69.8; Sta. 6, 70.9. Elevation of subgrade at Sta. 3 = 66.40; gradient = + 1.3%.

Ans. F 1.4; F .6; C 1.8; C 2.0; F .2; C .6

2. Sta. 31, 134.9; Sta. 32, 133.0; Sta. 32 + 70, 132.1; Sta. 33, 132.6; Sta. 33 + 55, 139.6; Sta. 34, 132.4; Sta. 35, 129.2. Elevation of subgrade at Sta. 31 = 133.61; gradient = − 1.22%.

Ans. C 1.3; C .6; C .6; C 1.4; C 9.1; C 2.4; C .5

3. Solve example 1, if the gradient is + 2% from Sta. 3 to Sta. 5 + 20, and − .40% beyond Sta. 5 + 20, the elevation of subgrade at Sta. 3 being 65.5 feet. Ans. F .5; F .4; C 1.3; C 1.4; C .1; C 1.3

4. Solve example 2, if the gradient is − 70% from Sta. 31 to Sta. 33 and + .10% beyond Sta. 33, and if the elevation of subgrade at Sta. 31 is 134.0 feet. Ans. C .9; F .3; F .7; 0.0; C 6.9; F .3; F 3.6

---

16. Slope Stakes.—For the purposes of earthwork, it is necessary to know where the sloping sides $a b$ and $c e$, Figs. 1 and 2, of a finished cut or fill intersect the natural surface of the ground. These points, determined as explained in the next article, are marked by stakes called **slope stakes.** The operation of locating the slope stakes is called **cross-sectioning.**

Thus, in Fig. 5, a slope stake will be driven at m and one at m'. These stakes are usually not driven vertically, but are leaned outwards from the center line. On the inner face of the stake at m, the cut $m k$ is written; and, similarly, on the inner face of the stake at m', the cut $m' k'$ is written. These two stakes, together with the center stake at c, furnish all the information that the contractor requires to guide him in excavating the section $m l l' m'$.

17. To Locate the Slope Stakes.—

Let b = width $l l'$, Fig. 5, of the roadbed;

d = depth $c e$ of the center stake;

s = slope ratio $= l k \div m k = l' k' \div m' k'$.

For the upper stake at m, let

x = distance mq from slope stake to center line;

$y + d$ = elevation of m above subgrade = $qc + ce = mk$.

Similarly, for the lower stake at m', let

x' = horizontal distance $m'q'$ from m' to center line;

$d - y'$ = $m'k'$ = elevation of m' above subgrade.

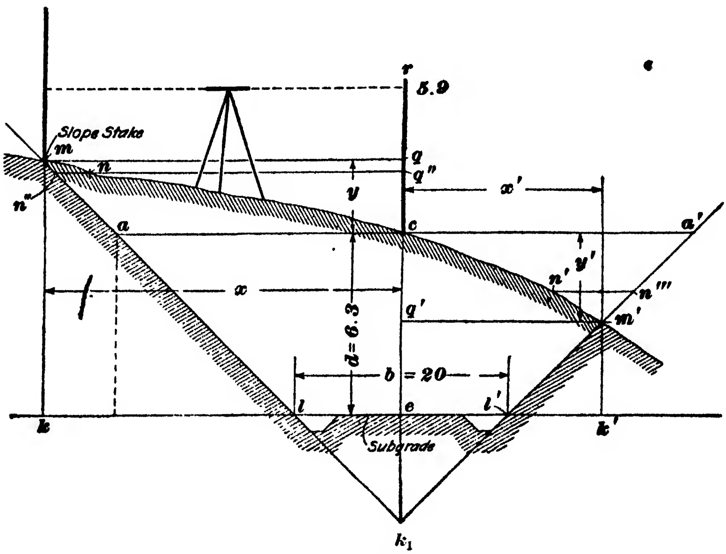


FIG. 5

Then, from the figure,

$$x = qm = ek = el + lk = \frac{b}{2} + mk \tan kml$$

$$= \frac{b}{2} + qe \tan kml = \frac{b}{2} + (d + y)\ s;$$

or,

$$x = \frac{b}{2} + sd + sy \qquad (1)$$

Similarly,

$$x' = \frac{b}{2} + sd - sy' \qquad (2)$$

If the natural surface mcm' is a level line, so that q, c, and q' are all at the same elevation, then, $y = 0$, $y' = 0$, and, therefore, by formulas **1** and **2**, and Fig. 5,

$$x = x' = ca = ca' = \frac{b}{2} + sd \qquad (3)$$

Formulas **1** and **2** are called **slope-stake equations;** formula **3** is called the **level-section equation.**

1. *To find the distance* $m\,q = x$ *from the upper slope stake to the center line.*

This distance cannot be found directly from formula **1**, because the value of the quantity y in this equation is not known until after the stake has been located. It is, therefore, found by successive trials as follows:

The required distance $m\,q$ is greater than the distance $c\,a$, and it is evident that the steeper the slope $m\,c\,m'$, the greater $m\,q$ will be. The rodman, carrying the rod and one end of the measuring tape, places the rod at some point n whose distance from c is, in his judgment, enough greater than the distance $a\,c$ computed by formula **3**, to bring the rod very near the required point m. The levelman reads the rod, and so finds the elevation of n above c; the rodman and his assistant then measure the distance from n to $c\,r$.

Let y'' be the measured elevation of n above the center stake c. Let x'' be the corresponding value of x computed by formula **1**; that is, let $x'' = \frac{b}{2} + s\,d + s\,y''$. This computed value of x'' is the distance $q''\,n''$, Fig. 5, from the center line to a point n'' of the slope whose elevation above the subgrade is equal to $y'' + d$. If the measured distance $q''\,n$ is less than the computed distance x'', the trial point n is evidently too near the center line, and the rod must be moved farther out; if the measured distance is greater than the computed distance, the rod must be moved farther in. Thus, by successive trials, a point is found for which the measured and computed values of x'' do not differ by more than .1 or .2 foot. This point will be, with sufficient approximation, the desired position of m. As an example, suppose that $d = 6.3$, and that the rod reading on c is 5.9. Suppose $s = 1.5 : 1$, and $b = 20$. Then, by formula **3**,

$$c\,a = \tfrac{20}{2} + 1.5 \times 6.3 = 19.5 \text{ feet}$$

The rodman will therefore hold the rod at some point more than 19.5 feet to the left of $c\,r$. Suppose that he holds

it 20 feet from $c\,r$, and that the reading on the rod in this position is 2.8. Then, the height of this point above c equals the reading on c minus the reading on n, or $5.9 - 2.8 = 3.1$ feet.

The computed distance from the rod to $c\,r$ is

$$\tfrac{20}{2} + 1.5 \times 6.3 + 1.5 \times 3.1 = 24.2 \text{ feet}$$

Since the measured distance (20 feet) is much smaller than this, the rod must be moved much farther out.

Suppose that the rod is carried out 7 feet, so that the measured distance to $c\,r$ is 27 feet, and suppose that the reading on the rod in this position is .8 foot. The elevation of this trial point above c will be $5.9 - .8 = 5.1$ feet, and, by formula **1**, the computed distance x'' is

$$\tfrac{20}{2} + 1.5 \times 6.3 + 1.5 \times 5.1 = 27.2 \text{ feet}$$

This agrees so closely with the measured distance that the slope stake may be driven at this point.

2. *To find the distance $m'q' = x'$ from the lower slope stake to the center line.*

The lower slope stake at m' is set in the same manner as the upper, except that the distance of each trial point below c is measured, and formula **2** is used in computing the corresponding value of x''. The distance of the trial point from $c\,r$ will in this case be taken less than the distance $c\,a'$ computed by formula **3**.

As in the preceding case, if the measured distance from $c\,r$ to the trial point is less than the computed distance, the point should be moved out; if greater, it should be moved in. This is evident from Fig. 5; if n' is the trial point, the computed distance x'' is the distance from $c\,r$ to that point n''' of the side slope whose elevation is equal to the elevation of n'. If the measured distance is less than the computed distance, the trial point is inside of the side slope k_1a', and it must therefore be moved out.

The selection of the trial point depends wholly on the judgment of the rodman. An experienced man will almost always locate the correct point at least on the second trial;

while some grow so expert that they can locate the majority of slope-stake points on the first trial.

18. Compound Sections.—Where the material to be excavated consists of a layer of earth resting on rock, the cross-section is called a **compound section.** A compound section is shown in Fig. 11. The slope ratio for the rock is less than for the earth; but, if the exact depths of the earth at the points k, a, b, and m, Fig. 11, were known, the slope stakes at k and m could be driven before any excavating had been done. As the slope of the rock and its depth below the surface are usually, however, known only very roughly, the method of setting the slope stakes in a compound section is generally as follows: The earth is first cleared away down to the rock for a width somewhat greater than that of the roadbed. Where the rock surface $a\,b$ is thus exposed, the slope stakes (or marks on the rock) at a and b are located, in the manner just described, for excavating the section $a\,d\,c\,b$. Slight **shelves** $b\,n$ and $a\,e$ are then usually cleared away on the rock to prevent in part the earth from washing into the cut. Marks are made on the rock at n and e, and finally the slope stakes m and k are set by finding by successive trials the positions of those points that satisfy the equations

$$ng = s \times gm$$
$$eg' = s \times kg'$$

in which s is the slope ratio for the earth.

EXAMPLES FOR PRACTICE

In each of the following examples, $b = 20$ feet, and $s = 1.5:1$. The letters refer to Fig. 5.

1. The depth at the center stake is 8.0 feet; the rod readings at c and n are 7.4 and 1.4, respectively. The measured distance from n to $c\,r$ is 30.5 feet. Should the trial point be moved out or in from the center line? Ans. It should be moved out slightly

2. In the preceding example, the rod reading at n' is 11.4 and the measured distance is 16.5 feet. Should the trial point be moved out or in? Ans. It should be moved in

3. The depth at the center stake is 2.0 feet; the rod reading on *c* is 4.6, and on *n*, 2.6. The measured distance from *n* to *c r* is 18.0 feet. Should the trial point be moved out or in?

Ans. It should be moved in

4. In the preceding example, the rod reading for the lower stake is 5.2, and the measured distance is 12.1 feet. Should the trial point be moved out or in?

Ans. Neither

---

19. The Form of Notes in Cross-Section Work. When each slope stake has been set as explained in the preceding article, its distance from the center line and the elevation of the stake above or below subgrade are entered in the field book in the form of a fraction. The numerator of this fraction is the distance of the stake above or below subgrade, and the denominator is the distance of the stake from the center line. Thus, if the slope stakes in the example of Art. **17** are set at Sta. 131, the complete entry in the notebook will be as follows:

Station	Subgrade	Elevation	Center Depth	Left	Right
132	162.40	159.7	F 2.7		
131	148.80	155.1	C 6.3	$\frac{\text{C } 11.4}{27.2}$	$\frac{\text{C } 2.3}{13.5}$
130	160.40	159.8	F .6		

The first four columns have been fully explained in Art. **15.** The fraction $\frac{\text{C } 11.4}{27.2}$ indicates that the left slope stake at *m*, Fig. 5, is 27.2 feet from the center line of the roadbed and 11.4 feet above subgrade. Similarly, the fraction $\frac{\text{C } 2.3}{13.5}$ indicates that the right slope stake *m'* is 13.5 feet to the right of the center line and 2.3 feet above subgrade. These expressions are called **slope-stake fractions.** It should be noticed that they are not true fractions in any sense. It is merely found convenient to write the cut or fill at each

slope stake and its measured distance from the center line in a fractional form.

Although an ordinary leveling rod may be used for setting slope stakes, the work may be done with sufficient accuracy with a light pine rod 2 inches wide, $\frac{7}{8}$ inch thick, and about 12 feet long, graduated into feet and tenths of a foot. This rod has no target, but is read directly with the telescope. It is light to carry, and if lost or damaged can easily be replaced at small cost.

COMPUTATIONS AND ESTIMATES

COMPUTATION OF VOLUME

20. Accuracy of Results Obtained.—The student should at the outset have a clear conception of the character of the work involved in earthwork surveys, and of the accuracy of the results obtainable. If material is to be excavated, it will have an upper surface *b e*, Fig. 2, that is more or less rough and irregular. Even if the excavation is made with perfectly regular slopes that form plane surfaces, yet, since the upper surface is irregular, the volume of earth cannot be exactly computed. Similarly, in a fill, since the natural surface *e b*, Fig. 1, is irregular, the volume of earth resting on *e b* cannot be found with perfect accuracy. In either case, it must be assumed that this mass of earth has a form that is practically identical with that of some geometrical solid whose volume can be exactly computed. It is true that this assumption involves some error; but the error can be reduced by taking a number of measurements sufficient to make the real volume approximate that of the assumed equivalent solid as closely as necessary. An attempt to compute the volume too closely may require an unwarranted expenditure of time and effort. Every road engineer should be able to judge what degree of accuracy is required in the surveys in order to determine the volume of the earthwork as closely as is necessary. It is never necessary to employ in the computation distances nearer than to the nearest tenth of a foot,

and it is very seldom necessary to compute volumes closer than to the nearest cubic yard.

21. Prismoids.—The definition of prismoid, the prismoidal formula, and the method of averaging end areas are given in *Geometry*, Part 2. The determination of volumes by both the prismoidal formula and the method of averaging end areas are further illustrated in *Hydrographic Surveying*.

If A_1 and A_2 are the areas of the bases of a prismoid; l, the perpendicular distance between them; and A_m, the area of a cross-section half way between the bases; the volumes V and V_1, as computed by the prismoidal formula and by the average end-area method, respectively, are

$$V = \frac{l}{6}(A_1 + 4A_m + A_2) \qquad (1)$$

$$V_1 = \frac{l}{2}(A_1 + A_2) \qquad (2)$$

The bases of the prismoid in railroad earthwork are such sections as $q\,t\,m\,p$, Fig. 7, made by vertical planes at right angles to the center line of the track. The length l of each prismoid is equal to the distance apart of the cross-sections. This is usually 100 feet, unless the surface of the ground is especially rough and irregular, when it becomes necessary to take sections at intervals of less than 100 feet. The prismoid will have four or more lateral surfaces, of which three are usually plane surfaces. The three plane surfaces are the roadbed $t\,m$, Fig. 7, which is usually a plane rectangle, and the two side slopes $t\,q$ and $m\,p$, which are usually plane surfaces in the form of trapezoids. The remaining surface $p\,q$ of the prismoid must be made to coincide with the actual surface of the ground as closely as possible.

22. Method of Calculation.—The determination of the volume by formula 2, Art. 21, will usually give fairly accurate results, and this method is even authorized by the laws of some American states. The prismoidal formula, however, should be used for all accurate work. This formula requires that the dimensions of the middle section whose area is A_m

shall be determined. This may be done by averaging the dimensions of the two bases and computing the area of the resulting figure. But a much simpler method is to compute the approximate volume by formula **2**, Art. **21**, and then, if necessary, to apply a correction to the result thus obtained. This correction, called the **prismoidal correction**, is the difference between the volume V computed by formula **1** and the volume V_1 computed by formula **2**; the result obtained by adding this correction to V_1 is the same as would have been obtained by a direct application of the prismoidal formula. The formula for computing the prismoidal correction will now be derived.

23. Volume and Prismoidal Correction for Triangular Prismoids.—A **triangular prismoid**, Fig. 6, is a prismoid in which the bases and all sections parallel to

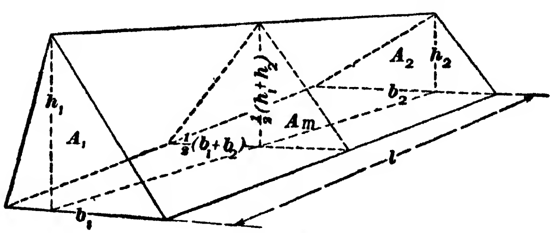


FIG. 6

them are triangles. Denoting the base and altitude of one end section by b_1 and h_1, respectively, the base and altitude of the other end section by b_2 and h_2, and the corresponding areas by A_1 and A_2, the following equations may be written:

$$A_1 = \tfrac{1}{2} b_1 h_1,\; A_2 = \tfrac{1}{2} b_2 h_2$$

The base and the altitude of the middle section, whose area is denoted by A_m, are, respectively, $\frac{1}{2}(b_1 + b_2)$ and $\frac{1}{2}(h_1 + h_2)$. Therefore,

$$A_m = \tfrac{1}{2} \times \frac{b_1 + b_2}{2} \times \frac{h_1 + h_2}{2} = \tfrac{1}{4} \times \frac{(b_1 + b_2)(h_1 + h_2)}{2}$$

Let the prismoidal correction, or the difference $V - V_1$, be denoted by C. This correction is to be added *algebraically*

to V_1 in order to obtain V. Substituting in formula **1**, Art. **21**, the values of A_1, A_2, A_m, we have

$$V = \frac{l}{6}(A_1 + 4A_m + A_2)$$
$$= \frac{l}{6}[\tfrac{1}{2}b_1h_1 + \tfrac{1}{2}(b_1 + b_2)(h_1 + h_2) + \tfrac{1}{2}b_2h_2]$$
$$= \frac{l}{12}(2b_1h_1 + 2b_2h_2 + b_1h_2 + b_2h_1)$$

Similarly, from formula **2**, Art. **21**,

$$V_1 = l \times \frac{A_1 + A_2}{2} = l \times \frac{\tfrac{1}{2}b_1h_1 + \tfrac{1}{2}b_2h_2}{2}$$
$$= \frac{l}{4}(b_1h_1 + b_2h_2) = \frac{l}{12}(3b_1h_1 + 3b_2h_2)$$

Therefore,

$$C = V - V_1$$
$$= \frac{l}{12}[2b_1h_1 + 2b_2h_2 + b_1h_2 + b_2h_1 - (3b_1h_1 + 3b_2h_2)]$$
$$= \frac{l}{12}(b_1h_2 - b_1h_1 + b_2h_1 - b_2h_2)$$
$$= \frac{l}{12}[b_1(h_2 - h_1) - b_2(h_2 - h_1)];$$

or, finally, $$C = \frac{l}{12}(b_1 - b_2)(h_2 - h_1) \qquad \textbf{(1)}$$

Also, $$V = V_1 + C \qquad \textbf{(2)}$$

It should be constantly borne in mind that C is to be added *algebraically* to V_1. If C is negative, this shows that the approximate volume V_1 is too large, and must be decreased; if C is positive, the approximate volume V_1 is too small, and must be increased.

A study of the correction will show that, if either the bases or the altitudes of the two end sections are equal, one of the factors $(b_1 - b_2)$ or $(h_2 - h_1)$ will become zero, and therefore the correction becomes zero. It shows also that, when one or both of these factors are small, the correction is a correspondingly small quantity; and that, when (as is usually the case) the breadth and height at one section are both smaller or both larger than the breadth and height at the other section, the correction is *negative*. Thus, if b_2 is less than b_1

and h_2 is less than h_1, then $b_1 - b_2$ is positive, $h_2 - h_1$ is negative, and, therefore, C is negative. But when C is negative, V_1 is greater than the true volume V; that is, the method of averaging end areas usually gives a result that is too large. When the difference of the breadths and heights is very large, the correction is very large, and V_1 is very greatly in error. Thus, for a pyramid, in which both b_2 and h_2 are zero, the correction is

$$\frac{l}{12}(b_1 - 0)(0 - h_1) = -\frac{b_1 h_1 l}{12}$$

The true volume is $\frac{1}{6} b_1 h_1 l$, and therefore the error in the value of V_1 is one-half, or 50 per cent., of the true volume. This extreme case shows the importance of computing the prismoidal correction when the areas of the bases are very unequal.

EXAMPLE.—The dimensions of the bases of a triangular prismoid are: $b_1 = 18$ feet, $h_1 = 8$ feet, $b_2 = 12$ feet, and $h_2 = 9$ feet. To find the volume of this prismoid, in cubic yards, if the length of the prismoid is one station.

SOLUTION.—The areas of the bases are:

$$A_1 = \tfrac{1}{2} \times 18 \times 8 = 72 \text{ sq. ft.}$$
$$A_2 = \tfrac{1}{2} \times 12 \times 9 = 54 \text{ sq. ft.}$$

Substituting these values in formula **2**, Art. **21**, and dividing by 27 to reduce to cubic yards,

$$V_1 = \tfrac{100}{2} \times (72 + 54) \div 27 = 233.33 \text{ cu. yd., nearly}$$

Substituting the given values in formula **1** above, and dividing by 27 to reduce to cubic yards,

$$C = \tfrac{100}{12} \times (18 - 12) \times (9 - 8) \div 27 = 1.85 \text{ cu. yd.}$$

Therefore, by formula **2**,

$$V = 233.33 + 1.85 = 235.18 \text{ cu. yd., or, say, } 235 \text{ cu. yd.} \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE

NOTE.—Results are given to the nearest cubic yard.

1. Solve the example in Art. **23** if $b_1 = 20$ feet, $h_1 = 10$ feet, $b_2 = 10$ feet, $h_2 = 5$ feet, and $l = 1$ station. Ans. $V = 216$ cu. yd.

2. If, in Fig. 5, $l l' = 20$ feet and $e k_1 = l_e \div s = 10 \div 1.5 = 6\frac{2}{3}$ feet, and if the other base of the prismoid is an exactly equal triangle 100 feet distant, find the number of cubic yards of earth in this triangular prismoid. What is the prismoidal correction for this prismoid?

Ans. $V = 247$ cu. yd.; $C = 0$

3. If $a\,a'\,k$, Fig. 5, is the base of a prismoid in which $a\,a' = 39$ feet and $c\,k = 13$ feet, and if, at the other base of the prismoid 100 feet distant, $a\,a' = 30$ feet and $c\,k = 10$ feet, find the volume of the triangular prismoid whose bases are the figures $a\,k\,a'$. Ans. $V = 739$ cu. yd.

---

24. Three-Level Sections.—Where the surface of the ground is fairly regular, it is sufficiently accurate to determine the elevation of the center point and the distance and elevation of the two slope stakes. The method assumes that the straight lines $c\,q$ and $c\,p$, Fig. 7, that join the center with the slope stakes are on the surface of the ground. When this method is used, the sections are called **three-level sections.**

In Fig. 7, and elsewhere throughout these earthwork calculations, b represents the width $t\,m$ of the roadbed; a, the depth $k\,n$ below the roadbed to where the two side-slope lines produced intersect; d, the center depth $c\,k$; and w_l and w_r the horizontal distances from the center to the left-hand and the right-hand slope stake, respectively. The triangle below the roadbed, with base b and altitude a, is called the **grade triangle**, and its area equals $\frac{1}{2}\,a\,b$. The altitude a is found from the relation (see Art. 8)

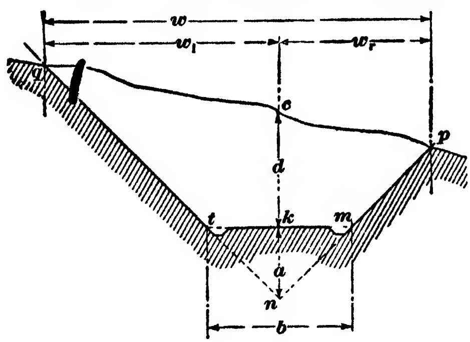


FIG. 7

$$a = n\,k = m\,k \cot m\,n\,k = \frac{m\,k}{\tan m\,n\,k} = \frac{\frac{1}{2}b}{s} \qquad (1)$$

If the area of the grade triangle is temporarily added to the area $t\,m\,p\,q$, the total area of the section $q\,n\,p$ may be considered as composed of the two triangles $p\,n\,c$ and $q\,n\,c$, both having the base $a + d$ and altitudes w_l and w_r, respectively. The respective areas of these triangles will therefore be $\frac{1}{2}(a + d)\,w_l$ and $\frac{1}{2}(a + d)\,w_r$. The area of the section $t\,m\,p\,q$ to be excavated is equal to the sum of the areas of these two

triangles minus the area of the grade triangle $t m n$. If the area of the section $t m p q$ is denoted by A_1, we shall have

$$
\begin{aligned}
A_1 &= \tfrac{1}{2}(a+d)(w_l+w_r) - \tfrac{1}{2}ab \\
&= \tfrac{1}{2}[(a+d)w - ab] \qquad (2)
\end{aligned}
$$

in which $w_l + w_r$ is denoted by w.

Similarly, if d' and w' denote the center depth and the total width, respectively, of the cross-section at the next stake of the center line, and A_2 denotes the area of this section, we shall have, since a and b have the same values at the two sections,

$$A_2 = \tfrac{1}{2}[(a+d')w' - ab] \qquad (3)$$

The approximate volume of the prismoid whose bases are the parallel sections $q t m p$ and whose length is the distance apart of the two sections is found by substituting the foregoing values of A_1 and A_2 in formula **2**, Art. **21**. This gives

$$
\begin{aligned}
V_1 &= \frac{l}{2}(A_1 + A_2) \\
&= \frac{l}{4}[(a+d)w + (a+d')w' - 2ab] \qquad \textbf{(1)}
\end{aligned}
$$

If the dimensions of the two cross-sections are very nearly equal, formula **1** will give a sufficiently accurate value of the volume of the prismoid; but if the two sections differ considerably, the approximate volume V_1 must be corrected by adding to it the prismoidal correction. This correction is computed as follows: Let C' be the prismoidal correction for the prismoid whose bases are the triangles $q c n$; C'', the prismoidal correction for the prismoid whose bases are the triangles $p c n$; and C''' the prismoidal correction for the prismoid whose bases are the grade triangles $t n m$. Let, also, V_1', V_1'', and V_1''' be the approximate values of the volumes of these three prismoids, respectively, computed by formula **2**, Art. **21**; and let V', V'', and V''' be the respective values computed by the prismoidal formula. An expression for C' is found by substituting in formula **1**, Art. **23**, $d + a$ for b_1, $d' + a$ for b_2, w_l for h_1, and w_l' for h_2. This gives

$$
\begin{aligned}
C' &= \frac{l}{12}(w_l - w_l')[(d'+a)-(d+a)] \\
&= \frac{l}{12}(w_l - w_l')(d'-d)
\end{aligned}
$$

In a similar manner,

$$C'' = \frac{l}{12}(w_r - w_r')(d' - d)$$

$$C''' = 0$$

Therefore, by formula **2**, Art. **23**,

$$V' = V_1' + C';\ V'' = V_1'' + C'';\ V''' = V_1''' + C'''$$

For the required volume V we have

$$V = V' + V'' - V''' = (V_1' + V_1'' - V_1''') + (C' + C'' - C''')$$

But $\quad V_1' + V_1'' - V_1''' = V_1$, and $V = V_1 + C$

Therefore, $\quad C = C' + C'' + C'''$

or, substituting the values of C', C'', C''', and reducing,

$$C = \frac{l}{12}(w - w')(d' - d) \qquad (2)$$

When the excavation is in earth and the difference between d and d' does not exceed 3 or 4 feet, formula **1** will usually give a sufficiently accurate result. If $d' - d$ exceeds 5 feet, or if the excavation is in rock, the prismoidal correction should be computed and applied.

25. Illustrative Example.—The form in which the computation of volume should be arranged when the cross-sections are three level sections is shown on page 23. The figures in the first four columns are written while the survey is being made, as was explained in Art. **19.** The figures in columns 5, 6, and 7 are used for computing the average-end area volume V_1 by formula **1,** Art. **24;** those in columns 8, 9, and 10 are employed in computing the prismoidal correction by formula **2,** Art. **24;** and the figures in the last two columns are used for computing the correction for curvature, as will be explained in a subsequent article.

The values of V_1 for the prismoids included between the successive cross-sections are found as follows: Since the results are always expressed in cubic yards, formula **1,** Art. **24,** becomes, for the volume between two full stations (l = 100),

$$V_1 = \frac{100}{4\times27}(a+d)w + \frac{100}{4\times27}(a+d')w' - \frac{2\times100}{4\times27}\times a\times b \qquad (1)$$

FORM OF NOTES FOR THREE-LEVEL GROUND

1 Station	2 Center Depth	3 Left	4 Right	5 $(a+d)$	6 w	7 Volumes (a)	7 Volumes (b)	8 $w - w'$	9 $d' - d$	10 Prismoidal Correction C	11 $x_l - x_r$	12 Curvature Correction
25	C 2.4	$\frac{C\ .6}{11.9}$	$\frac{C\ 4.7}{18.0}$	9.7	29.9	269	426	+18.1	−5.7	−21	− 6.1	− 2
24 + 35	C 8.1	$\frac{C\ 5.9}{19.9}$	$\frac{C\ 11.4}{28.1}$	15.4	48.0	684	531	+16.0	−3.7	− 6	− 8.2	− 3
24	C 11.8	$\frac{C\ 8.8}{24.2}$	$\frac{C\ 19.2}{39.8}$	19.1	64.0	1,132	1,601	−14.4	+2.4	−11	−15.6	−11
23	C 9.4	$\frac{C\ 4.8}{18.2}$	$\frac{C\ 13.6}{31.4}$	16.7	49.6	767	1,048	− 3.3	+3.2	− 3	−13.2	− 7
22	C 6.2	$\frac{C\ 3.4}{16.1}$	$\frac{C\ 12.8}{30.2}$	13.5	46.3	579					−14.1	
										−41		−24

Volume by average end areas 3,606
Prismoidal correction −41
Volume by prismoidal formula 3,565

Roadbed 22 feet wide. Slope ratio = 1.5 to 1. 7° curve to the right.

If the slope is $1\frac{1}{2}:1$ and the width of the roadbed is 22 feet, we have, by equation (1), Art. **24**,

$$a = \frac{\frac{1}{2} \times 22}{\frac{3}{2}} = 7.3, \text{ for all sections}$$

The sums of the constant depth a and the variable depths d in the second column are written in the fifth column. Thus, at Sta. 22, $a + d = 7.3 + 6.2 = 13.5$ feet; at Sta. 23, $a + d = 7.3 + 9.4 = 16.7$ feet. The total width at each station is written in the sixth column. Since, in Fig. 7, $w = w_l + w_r$, and since the measured distances w_l and w_r are the denominators of the fractions in columns 3 and 4, respectively, it is only necessary to add the two denominators at each station to obtain the numbers in column 6. Thus, at Sta. 22, $w = 16.1 + 30.2 = 46.3$; at Sta. 23, $w = 18.2 + 31.4 = 49.6$ feet.

To compute the value of V_1 between Sta. 22 and Sta. 23, the proper values must be substituted in formula **1**. This gives

$$V_1 = \frac{100}{4 \times 27} \times 13.5 \times 46.3 + \frac{100}{4 \times 27} \times 16.7 \times 49.6$$
$$- \frac{2 \times 100}{4 \times 27} \times 7.3 \times 22 = 579 + 767 - 298 = 1{,}048 \text{ cu. yd.}$$

The number 579 is written in column 7 (a) opposite Sta. 22, and 767 in the same column opposite Sta. 23. The result, 1,048 cubic yards, is written opposite Sta. 23 in column 7 (b).

In a similar manner, we have, for the volume of the prismoid between Sta. 23 and Sta. 24,

$$V_1 = \frac{100}{4 \times 27} \times 16.7 \times 49.6 + \frac{100}{4 \times 27} \times 19.1 \times 64$$
$$- \frac{2 \times 100}{4 \times 27} \times 7.3 \times 22$$

The first term of this expression has already been computed, and its value, 767 cubic yards, has been written in column 7 (a) opposite Sta. 23. The last term is the constant volume 298 cubic yards. It is therefore necessary to compute the second term only. Its value is found to be 1,132 cubic yards, and this is written in column 7 (a) opposite Sta. 24. We then have

$$V_1 = 767 + 1{,}132 - 298 = 1{,}601 \text{ cubic yards,}$$

and this result is written in column 7 (b).

It is thus seen that, at each station, it is necessary to compute but one term of formula **1**; this term is the value of $\frac{100}{4 \times 27}(a + d)\,w$ for that station. The value of this term for each station is written in column 7 (a). If the stations are 100 feet apart, any number in column 7 (b) is obtained by adding the two preceding numbers in column 7 (a) and subtracting 298 cubic yards from the resulting sum. The result so obtained is the value of V_1 for a prismoid 100 feet long. But if the two stations are less than 100 feet apart, the result must be multiplied by the ratio of their distance to 100 feet to obtain the volume of the prismoid. This volume is then written in column 7 (b). For example, for the prismoid between Sta. 24 and Sta. 24 + 35, we should obtain, if the prismoid were 100 feet long,

$$1{,}132 + 684 - 298 = 1{,}518 \text{ cubic yards}$$

Since the length is but 35 feet, the actual value of V_1 is

$$\tfrac{35}{100} \times 1{,}518 = 531 \text{ cubic yards,}$$

and this number is written in column 7 (b).

It is usually more convenient to compute all the numbers in each column before passing on to the next column. When column 7 (b) has been filled up, the number of this column opposite each station is the approximate number of cubic yards, computed by average end areas, contained between that station and the preceding station. Thus, 1,048 is the approximate number of cubic yards between Sta. 23 and Sta. 22; 531 is the approximate number between Sta. 24 + 35 and Sta. 24; etc. The total approximate number of cubic yards, between Sta. 22 and Sta. 25, as computed by average end areas, is, therefore,

$$1{,}048 + 1{,}601 + 531 + 426 = 3{,}606 \text{ cubic yards}$$

The prismoidal correction must now be computed.

Since the result is to be expressed in cubic yards, formula **2**, Art. **24**, becomes

$$C = \frac{l}{12 \times 27}(w - w')(d' - d) \qquad \textbf{(2)}$$

The successive values of $w - w'$ in column 8 are obtained by subtracting each number in column 6 from the number

just below it in this column. Thus, for the prismoid between Sta. 22 and Sta. 23, $w = 46.3$, $w' = 49.6$; and $w - w' = -3.3$ feet. Similarly, the values of $d' - d$ in column 9 are obtained by subtracting each number in column 2 from the number just above it in this column. Thus, for the first prismoid, $d = 6.2$, $d' = 9.4$, and $d' - d = +3.2$ feet.

The numbers in column 10 are the values of the prismoidal correction computed by formula **2**. Thus, for the first prismoid, since $l = 100$,

$$C = \frac{100}{12 \times 27} \times -3.3 \times 3.2 = -3 \text{ cubic yards;}$$

for the second prismoid,

$$C = \frac{100}{12 \times 27} \times -14.4 \times 2.4 = -11 \text{ cubic yards;}$$

and similarly for the remaining prismoids.

The volume of the first prismoid, as obtained by the prismoidal formula, is, therefore, $1{,}048 - 3 = 1{,}045$ cubic yards; that of the second, $1{,}601 - 11 = 1{,}590$ cubic yards, etc.

EXAMPLES FOR PRACTICE

1. In the example just given, compute the volume of the prismoid between Sta. 24 and Sta. 24 + 35. Ans. $V_1 = 531$; $V = 525$ cu. yd.

2. In the foregoing example, compute the volume of the prismoid between Sta. 24 + 35 and Sta. 25. Ans. $V_1 = 426$; $V = 405$ cu. yd.

3. If the roadbed to which the accompanying notes refer is 21 feet wide and the slope is $1\frac{1}{2} : 1$, find the volume of the prismoid between Sta. 161 and Sta. 162.

Station	Center Depth	Left	Right
163	C 4.6	$\frac{C\,2.4}{14.1}$	$\frac{C\,0.0}{10.5}$
162	C 4.6	$\frac{C\,2.1}{13.6}$	$\frac{C\,4.1}{16.6}$
161	C 2.1	$\frac{C\,4.0}{16.5}$	$\frac{C\,6.1}{19.6}$

Ans. $V_1 = 356$; $V = 361$ cu. yd.

26. Irregular Sections.—The method of three-level sections is always sufficiently accurate for preliminary work; and, when the surface of the ground is fairly regular, it is sufficiently accurate for the final computations. When, however, the surface of the ground is very irregular, it becomes necessary, in order to obtain the volume with reasonable accuracy, to measure the distance from the center to various points in the cross-section where the slope changes, and to obtain the elevations of those points above the roadbed. This produces what is called an **irregular section,** such as is illustrated in Fig. 8. If two such sections form the bases of a prismoid, the volume can be computed by applying the prismoidal formula, or by using the method of averaging end areas, and then applying a prismoidal correction equal to the sum of the corrections for the different elementary triangular prismoids into which the irregular prismoid may be divided. While this method is theoretically applicable, and is sometimes adopted, it is usually considered a needless refinement. As a compromise between this method of extreme accuracy and the too rough method of averaging end areas, a prismoidal correction is usually computed by treating the bases, *for the purpose of this computation only*, as three-level sections. This gives only an approximate value of the correction, but a value that is generally very nearly exact.

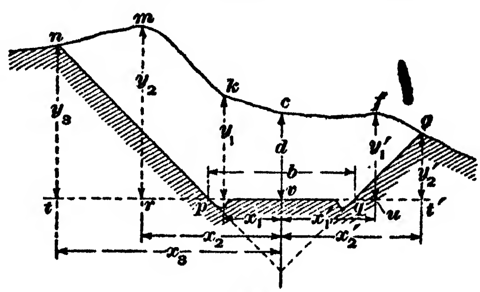


FIG. 8

The irregular section shown in Fig. 8 has two intermediate points m and k on one side of the center, and one intermediate point f on the other. The distances out and the heights of the points above the roadbed are as shown. The lines cf, fg, ck, etc. are treated as straight lines. Denoting a trapezoid by the letters in two diagonally opposite vertexes, we have, for the area A of the section $npqgfckm$,

A = trapezoid $n\,r$ + trapezoid $r\,k$ + trapezoid $k\,v$ + trapezoid $c\,u$ + trapezoid $f\,t'$ − triangle $n\,t\,p$ − triangle $g\,q\,t'$;

or, writing the expressions for these areas in order,

$$A = \tfrac{1}{2}(y_3 + y_2)(x_3 - x_2) + \tfrac{1}{2}(y_2 + y_1)(x_2 - x_1) + \tfrac{1}{2}(y_1 + d)x_1 + \tfrac{1}{2}(y_1' + d)\,x_1' + \tfrac{1}{2}(y_2' + y_1')\,(x_2' - x_1') - \tfrac{1}{2}\left(x_3 - \frac{b}{2}\right)y_3 - \tfrac{1}{2}\left(x_2' - \frac{b}{2}\right)y_2'$$

Performing the operations indicated and rearranging the terms,

$$A = \tfrac{1}{2}\left(\tfrac{1}{2}b\,y_3 + x_3 y_2 + x_2 y_1 + x_1 d + d\,x_1' + y_1' x_2' + \tfrac{1}{2}b\,y_2' - y_3 x_2 - y_2 x_1 - x_1' y_2'\right)$$

This long expression for the area may be very easily formed as follows: Write the successive slope-stake fractions (Art. 19) in order, in a horizontal row, beginning with the extreme left slope stake; and for the center stake write the fraction $\frac{d}{0}$. At the beginning and end of the row, write the fraction $\frac{0}{\frac{1}{2}b}$. Thus, the fraction for the stake at n is $\frac{y_3}{x_3}$; for the point m, it is $\frac{y_2}{x_2}$, etc.; so that the row of fractions for Fig. 8 will be as follows:

$$\frac{0}{\frac{1}{2}b} \times \frac{y_3}{x_3} \times \frac{y_2}{x_2} \times \frac{y_1}{x_1} \times \frac{d}{0} \times \frac{y_1'}{x_1'} \times \frac{y_2'}{x_2'} \times \frac{0}{\frac{1}{2}b}$$

Next, multiply each denominator by the numerator that follows it and each numerator by the denominator that follows it, giving to those products connected with full lines the plus sign, and to those connected with dotted lines the minus sign. One-half of the algebraic sum of these products will be the desired area. This is evident, since, proceeding according to the directions, we have the positive products

$$\tfrac{1}{2}b\,y_3,\ x_3 y_2,\ x_2 y_1,\ x_1 d,\ d\,x_1',\ y_1' x_2',\ \text{and } y_2'\,\tfrac{1}{2}b;$$

and the negative products

$$-y_3 x_2,\ -y_2 x_1,\ \text{and } -x_1' y_2'$$

One-half of the algebraic sum of these is identical with the second member of the formula given above.

EXAMPLE.—The following notes having been recorded at Sta. 129; it is required to find the area of the cross-section. The roadbed is 24 feet wide.

STATION	CENTER DEPTH	LEFT			RIGHT	
129	C 8.3	$\frac{C\ 12.7}{31.0}$	$\frac{C\ 16.0}{15.0}$	$\frac{C\ 12.2}{10.5}$	$\frac{C\ 4.1}{8.2}$	$\frac{C\ 6.0}{21.0}$

SOLUTION.—The series of fractions will be as follows:

$$\left(\frac{0}{12}\right) \times \frac{12.7}{31.0} \times \frac{16.0}{15.0} \times \frac{12.2}{10.5} \times \left(\frac{8.3}{0}\right) \times \frac{4.1}{8.2} \times \frac{6.0}{21.0} \times \left(\frac{0}{12}\right)$$

These are exactly as written in the field book, except that the fraction $\frac{0}{\frac{1}{2}b} = \frac{0}{12}$ is written at the beginning and end of the row; and that for the center stake the fraction $\frac{d}{0} = \frac{8.3}{0}$ is written. The double areas, computed according to the rule, are as follows:

PLUS AREAS		MINUS AREAS	
$12 \times 12.7 =$	152.4	$12.7 \times 15.0 =$	190.5
$31.0 \times 16.0 =$	496.0	$16.0 \times 10.5 =$	168.0
$15.0 \times 12.2 =$	183.0	$8.2 \times 6.0 =$	49.2
$10.5 \times 8.3 =$	87.2	Sum $=$	407.7
$8.3 \times 8.2 =$	68.1		
$4.1 \times 21.0 =$	86.1		
$6.0 \times 12.0 =$	72.0		
Sum $=$	1144.8		

The desired area is, therefore,

$$\tfrac{1}{2}(1{,}144.8 - 407.7) = 368.6 \text{ sq. ft.} \quad \text{Ans.}$$

27. In computing the area, the line of fractions in the statement of the preceding example need not be copied from the field book. It is only necessary to write in with a lead pencil the three additional fractions of the series in the solution, which are enclosed in parenthesis, and then to form the products. After a very little practice, the student will avoid writing these fractions, merely *imagining* them to be written. The full and dotted lines of series in the solution should not be drawn on the page of the field book.

This general method for irregular sections applies to all sections, no matter at how many points n, m, k, etc.,

Fig. 8, readings are taken. If preferred, it may therefore be used for three-level sections in place of the method of Art. 24.

28. Illustrative Example: Tabulation of Data and Results.—The data and results in the following example are given in tabular form, as before, but with even greater reason on account of its greater complexity; yet, the method is but an extension of the method previously used for three-level ground. Two tables are given—(A) and (B): the first is merely a copy of the field notes, which are here made separate from the computations, since both of them require considerable space. The form of the field notes should be carefully observed.

(A)

FIELD NOTES

1 Station	2 Center Cut or Fill	3 Left	4 Right
129	C 8.3	$\frac{C\,12.7}{31.0}$ $\frac{C\,16.0}{15.0}$ $\frac{C\,12.2}{10.5}$	$\frac{C\,4.1}{8.2}$ $\frac{C\,6.0}{21.0}$
+40	C 13.2	$\frac{C\,22.8}{46.2}$ $\frac{C\,20.4}{31.0}$ $\frac{C\,18.2}{19.5}$	$\frac{C\,12.8}{13.7}$ $\frac{C\,10.4}{27.6}$
128	C 10.9	$\frac{C\,18.6}{39.9}$	$\frac{C\,8.0}{4.2}$ $\frac{C\,8.5}{21.7}$
127	C 8.6	$\frac{C\,14.6}{33.9}$	$\frac{C\,12.4}{30.6}$
126	C 4.2	$\frac{C\,9.6}{26.4}$	$\frac{C\,2.1}{15.1}$

Roadbed 24 feet wide in cut. Slope 1.5 : 1.

In column 1 of Table (A) is given the station number of the section; it should be observed that the notes run from the bottom of the page upwards. The notes are arranged in this way so that, when one stands on the line of the road looking forwards, the fractional expressions, which give for

(B)

Computation

1	2	3	4		5	6	7	8
Station	Double Plus Areas	Double Minus Areas	Cubic Yards (a)	Cubic Yards (b)	w	$w - w'$	$d' - d$	Prismoidal Correction
129	152.4 496.0 183.0 87.2 68.1 86.1 72.0	190.5 168.0 49.2	683	1,214	52.0	+ 21.8	− 4.9	− 20
128 + 40	273.6 942.5 564.2 257.4 180.8 353.3 124.8	706.8 397.8 142.5	1,342	886	13.8	− 72.2	+ 2.3	− 3
128	223.2 434.9 45.8 173.6 102.0	35.70	874	1,688	61.6	+ 2.9	+ 2.3	+ 2
127	175.2 291.5 263.2 148.8		814	1,105	64.5	− 23.0	+ 4.4	− 31
126	115.2 110.9 63.4 25.2		291		41.5			

$V_1 = 4{,}893$ −52

$C = -52$

$V = 4{,}841$

each point the height and distance from the center, will have on the notebook approximately the same relative position as they have on the ground. Column 2 contains the center cut or fill, each number being preceded by F or C, to indicate fill or cut, respectively. The slope-stake figures for the left-hand side are always given at the extreme left of the space in column 3. The line between columns 3 and 4 may then represent the center line, and the intermediate points between the left-hand slope stake and the center are given in their order in column 3. Similarly, the points on the right side are placed in column 4; the figures for the right-hand slope stake are always placed in the extreme right-hand side of that column.

Table (B) shows the computation arranged in tabular form. In the first column are the station numbers; in the second are the double plus areas; and in the third are the double minus areas. From formula **2**, Art. **21**, the volume V_1, in cubic yards, of the prismoid between two full stations is given by the equation

$$V_1 = \frac{100}{2 \times 27} \times A_1 + \frac{100}{2 \times 27} \times A_2$$

In column 4 (a), opposite each station, is given the value of $\frac{100}{2 \times 27} \times A$ for that station. The sum of any two successive numbers in column 4 (a) is the volume V_1 of the prismoid between the corresponding sections, if this prismoid is 100 feet long; otherwise, this sum must be multiplied by the ratio of the length of the prismoid to 100 feet. The resulting volume is written in column 4 (b). The last four columns contain the computation of the prismoidal correction, performed as explained in Art. **25**.

To show clearly how the table is formed, the computation of the volume of the prismoid between Sta. 128 + 40 and Sta. 129 will now be given in full. To find the end area at Sta. 128 + 40, the following fractions are written:

$$\frac{0}{12.0} \quad \frac{22.8}{46.2} \quad \frac{20.4}{31.0} \quad \frac{18.2}{19.5} \quad \frac{13.2}{0} \quad \frac{12.8}{13.7} \quad \frac{10.4}{27.6} \quad \frac{0}{12.0}$$

The products of the numbers connected by full lines, 12.0×22.8, 46.2×20.4, etc., are written in column 2, and the products of those connected by dotted lines, 22.8×31.0, 20.4×19.5, etc., are written in column 3. The sum of the double plus areas is 2,696.6, and the sum of the double minus areas is 1,247.1. The area of the section is, therefore, $\frac{1}{2} \times (2{,}696.6 - 1{,}247.1) = 724.8$ square feet. The product, $\frac{100}{2 \times 27} \times 724.8 = 1{,}342$ cubic yards is written in column 4 (*a*) of the table.

From the example in Art. **26** the area of the section at Sta. 129 is 368.6 square feet; the product $\frac{100}{2 \times 27} \times 368.6 = 683$ is written in column 4 (*a*) opposite Sta. 129.

If the prismoid were 100 feet long, the volume V_1 would be $683 + 1{,}342 = 2{,}025$ cubic yards. As the prismoid is but 60 feet long, the volume is $\frac{60}{100} \times 2{,}025 = 1{,}215$ cubic yards, and this number is written in column 4 (*b*) opposite Sta. 129.

The computation for the other stations is made in a similar way. It will be observed that the sections at Sta. 126 and Sta. 127 are three-level sections, and that in this case there are no minus areas.

The sum of the numbers in column 4 (*b*) is 4,894 cubic yards, and this is the volume V_1 of the prismoid between Sta. 126 and Sta. 129. The total prismoidal correction, obtained as explained in Art. **25**, is -52 cubic yards. Therefore, the final volume V is $4{,}894 - 52 = 4{,}842$ cubic yards.

EXAMPLES FOR PRACTICE

1. Find the volume of the prismoid between Sta. 127 and Sta. 128 in the example just given.
Ans. $V_1 = 1{,}688$; $C = +2$; $V = 1{,}690$ cu. yd.

2. Find the volume of the prismoid between Sta. 128 and Sta. 128 + 40 in example 1. Ans. $V_1 = 886$; $C = -3$; $V = 883$ cu. yd.

3. Solve example 1 of Art. **25** by the method of this article.
Ans. $V_1 = 531$; $C = -6$; $V = 525$ cu. yd.

4. Having given the following field notes, find the volume of the prismoid between Sta. 21 and Sta. 22, if the roadbed is 20 feet wide:

Station	Center Depth	Left		Right	
22	C 6.5	$\frac{C\,4.1}{16.1}$	$\frac{C\,5.0}{8.0}$	$\frac{C\,2.0}{8.0}$	$\frac{C\,7.5}{21.2}$
21	C 5.3	$\frac{C\,6.2}{19.3}$	$\frac{C\,6.0}{12.0}$	$\frac{C\,4.0}{10.0}$	$\frac{C\,8.9}{23.3}$

Ans. $V_1 = 522$; $C = +2$; $V = 524$ cu. yd.

29. Areas of End Sections in Side-Hill Work. When the grade line runs pretty close to the surface along a side slope, it will usually happen that both cut and fill will be necessary in the same section. In such a case, it is frequently sufficiently accurate to consider that the section in either cut or fill is triangular. Thus, in Fig. 9, if the

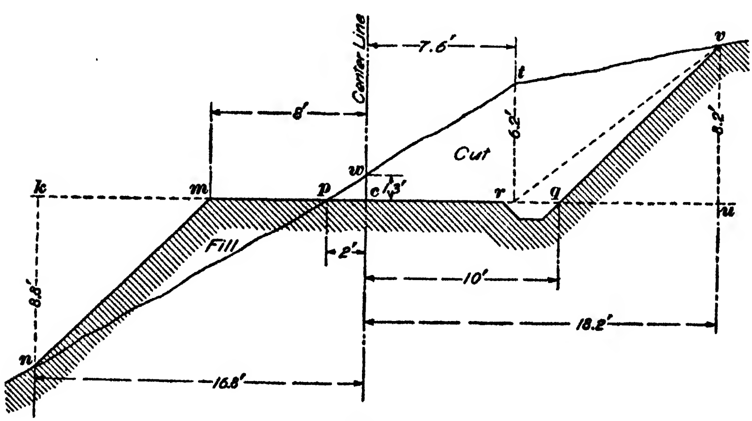


FIG. 9

slope from p to v were uniform, the area of the cut would be the area of the triangle $p\,q\,v$, and that of the fill would be the area of the triangle $p\,m\,n$. If there is an intermediate point t, however, the method of Art. **26** should be employed

to obtain the area of the section $pqvt$. Although the amount of earthwork to be done in side-hill work is usually very small, yet, as previously stated, the method of averaging end areas is generally very inaccurate, the prismoidal correction being a very large percentage of the total volume, frequently as much as one-third of the nominal volume.

As an illustration, suppose that in Fig. 9 the shoulder m of the slope is 8 feet from the center, that the fill begins at 2 feet from the center, and is a rock fill with a slope of 1 : 1; and that the slope stake n is 16.8 feet from the center. Then, $mk = ck - cm = 16.8 - 8.0 = 8.8$ feet; and, since the slope $nk \div km$ is 1 : 1, the vertical distance nk of n below subgrade will also be 8.8 feet. Assuming it to be sufficiently accurate to treat pn as a straight line, it may be considered that the section of fill is the triangle mnp, whose base mp equals $8.0 - 2.0 = 6.0$ feet and whose altitude is nk.

The area $pqvt$ is found by the formula in Art. **26**. The fraction for the point p is $\frac{0}{2}$; that for t is $\frac{C\,6.2}{7.6}$; and that for v is $\frac{C\,8.2}{18.2}$. The center depth is 1.3 feet, and the distance $cq = \frac{1}{2}b$ is 10 feet. The notes for the entire section shown in Fig. 9 will therefore be as given in the following table:

Station	Center Depth	Left		Right	
33	C 1.3	$\frac{F\,8.8}{16.8}$	$\frac{0}{2.0}$	$\frac{C\,6.2}{7.6}$	$\frac{C\,8.2}{18.2}$

The series of fractions will therefore be, considering only the section of cut,

$$\frac{0}{10} \quad \frac{0}{2} \quad \frac{1.3}{0} \quad \frac{6.2}{7.6} \quad \frac{8.2}{18.2} \quad \frac{0}{10}$$

The double areas are as follows:

Plus Areas	Minus Areas
2.6	6 2.3
9.9	
1 1 2.8	
8 2.0	
Sum = 2 0 7.3	

The desired area for cut is, therefore,

$$\tfrac{1}{2} \times (207.3 - 62.3) = 72.5 \text{ square feet}$$

30. Computation of Volumes in Side-Hill Work. The volumes of the prismoids for cut and for fill will be computed separately. The areas of the bases of each prismoid are first found as explained in Art. **29**, and the volumes V_1 are computed by the formula

$$V_1 = \frac{l}{2}(A_1 + A_2)$$

To find the prismoidal correction, it is sufficiently accurate to regard, *for the purpose of computing this correction only*, the bases of the prismoids as triangles, and to compute the prismoidal correction by formula **1**, Art. **23**.

Example.—It is required to compute from the following notes the volume of cut and fill, the roadbed being 20 feet wide in cuts and 16 feet wide in fills (see Fig. 9):

Station	Center Depth	Left		Right		
33	C 1.3	$\frac{\text{F } 8.8}{16.8}$	$\frac{0}{2.0}$		$\frac{\text{C } 6.2}{7.6}$	$\frac{\text{C } 8.2}{18.2}$
32	F 2.0	$\frac{\text{F } 11.4}{19.4}$		$\frac{0}{3.4}$	$\frac{\text{C } 3.3}{11.6}$	$\frac{\text{C } 6.0}{16.0}$

Solution.—At Sta. 32, the distance cp = 3.4 ft., and p is on the right of c. Hence, the base pm of the triangle of fill = 8.0 + 3.4 = 11.4 ft. Since nk = 11.4 ft., the area of this triangle is $\frac{1}{2} \times 11.4 \times 11.4$ = 65.0 sq. ft., area of fill.

To compute the area of the cut, we write the series

$$\frac{0}{3.4} \times \frac{3.3}{11.6} \times \frac{6.0}{16.0} \times \frac{0}{10}$$

and obtain:

	Double Plus Areas	Double Minus Areas
	5 2.8	6 9.6
	6 0.0	1 1.2
Sum =	1 1 2.8	8 0.8

Hence, the area is $\frac{1}{2}(112.8 - 80.8) = 16.0$ sq. ft. (cut).

For Sta. 33, we have found in the example of Art. **29**,

area of fill = 26.4 sq. ft.; area of cut = 72.5 sq. ft.

The volume V_1 of fill will therefore be

$$\frac{100}{2 \times 27} \times (26.4 + 65.0) = 169 \text{ cu. yd. (fill)}$$

and that of cut,

$$\frac{100}{2 \times 27} \times (16.0 + 72.5) = 164 \text{ cu. yd. (cut)}$$

The prismoidal correction must now be computed. By formula **1**, Art. **23**, we obtain,

$$\text{for fill, } C = \frac{100}{12 \times 27} \times (11.4 - 6.0) \times (8.8 - 11.4) = -4 \text{ cu. yd.}$$

$$\text{for cut, } C = \frac{100}{12 \times 27} \times (6.6 - 12) \times (8.2 - 6) = -4 \text{ cu. yd.}$$

The final corrected volumes are, therefore,

$$\left.\begin{array}{l}\text{for fill, } V = 169 - 4 = 165 \text{ cu. yd.}\\ \text{for cut, } V = 164 - 4 = 160 \text{ cu. yd.}\end{array}\right\}\text{Ans.}$$

EXAMPLES FOR PRACTICE

1. Draw a figure showing the cross-section at Sta. 32 in the example just given; obtain an expression for the area of the cut as in Art. **26**, and thus show that the employment of the series in the foregoing example will give the correct area.

2. If, in the foregoing example, the field notes at Sta. 34 are as given in the accompanying table, find the volumes of the prismoids of cut and fill between Sta. 33 and Sta. 34.

$$\text{Ans.}\begin{cases}\text{For fill, } V_1 = 77,\ C = 1;\ V = 78 \text{ cu. yd.}\\ \text{For cut, } V_1 = 312;\ C = -1;\ V = 311 \text{ cu. yd.}\end{cases}$$

Station	Center Depth	Left	Right
34	C 4.0	$\frac{\text{F } 10.0}{18.0}$ $\frac{0}{5}$	$\frac{\text{C } 9.4}{19.4}$

31. Transition From Cut to Fill.—At each transition from cut to fill, the cross-section of cut gradually diminishes to zero, and the fill, commencing at zero, increases to the full-sized embankment. There is, therefore, a terminal pyramid at the end of the cut, and a similar pyramid at the beginning of the fill. A cross-section should be taken where either side of the roadbed first runs out of the cut, as the point *b* in Fig. 10. The section at that point will be a triangle, and the remainder of the cut will be a pyramid

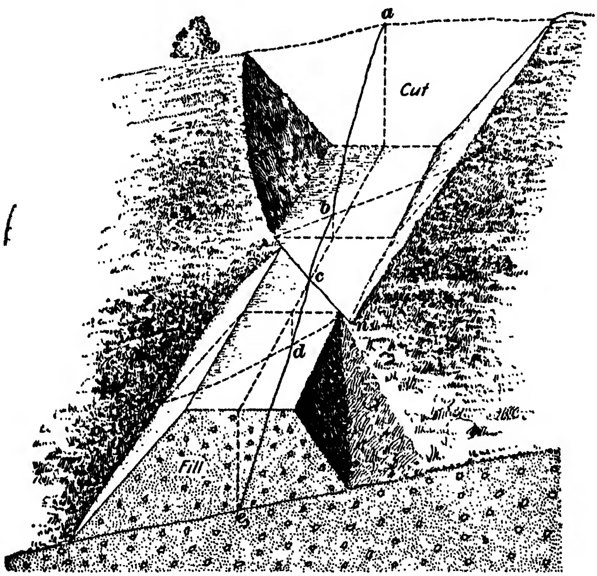


FIG. 10

whose vertex is the point *n*, where the other side of the cut reaches the surface. The initial pyramid of fill overlaps the terminal pyramid of cut for practically its whole length, the only discrepancy being that the width of the roadbed in the cut is greater than that in the fill, and therefore the apex of the pyramid of fill is not at the base of the pyramid of cut. A cross-section of the fill should be taken at the point *n*, where the roadbed attains its full width in fill. The volume of each of these terminal pyramids equals the area of its triangular base multiplied by one-third of the height, or

length. Beyond these terminal pyramids, the volume of cut or fill can be determined by the usual methods.

32. Compound Sections.—When the excavation for a cut passes partly through earth and partly through rock, it may be justifiable to use different slope ratios and different forms of cross-section, as is illustrated in Fig. 11. When estimates are being made to determine the amount of earthwork, it is sometimes required that borings shall be made to determine whether rock will be encountered before the excavation is carried to its full depth. During construction, the earth is dug away until rock is exposed; and after excavating

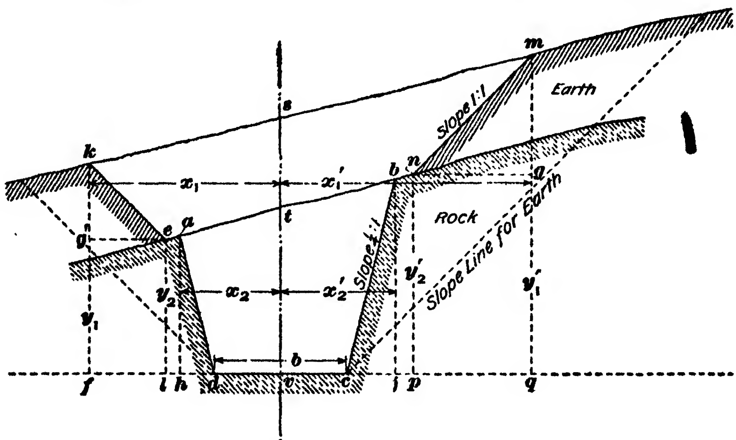


FIG. 11

into the rock to the desired depth, and using such slopes as are found necessary, the earth slopes are finally determined. Although it may be seen that there is a considerable economy so far as mere volume of excavation is concerned when rock is encountered, yet, since rock is more expensive to excavate, it frequently makes but little difference in the cost whether rock is found or not. The largely increased cross-section of earth tends to compensate for the reduced cost per cubic yard of excavating the earth.

The computation of the volume of earthwork between compound cross-sections is much more complicated than when the excavation is of only one class of material. The

area of the earthwork and the rockwork at each section must be determined separately. It is very difficult, if not impossible, to make preliminary computations, before any excavating has been done, of the precise amount of rockwork and earthwork, since they can only be made in a blind way by boring. It is necessary to know just where the rock sections "run out," and this cannot ordinarily be determined until after the excavation has been completed.

When the excavation has been completed, the areas of the end sections are determined as follows:

To find the area of $abcd$, Fig. 11, of the rock section, we have, from the figure (assuming $ah = el$, $bj = np$, which is sufficiently close),

$$\begin{aligned}\text{area } abcd &= \text{trapezoid } aj - \text{triangle } ahd - \text{triangle } bjc \\ &= \tfrac{1}{2}(y_2 + y_2')(x_2 + x_2') - \tfrac{1}{2}(x_2 - \tfrac{1}{2}b)y_2 \\ &\qquad - \tfrac{1}{2}(x_2' - \tfrac{1}{2}b)y_2' \\ &= \tfrac{1}{2}(\tfrac{1}{2}by_2 + x_2y_2' + y_2x_2' + \tfrac{1}{2}by_2') \qquad (1)\end{aligned}$$

This expression may be easily formed by a method similar to that explained in Art. 26. Thus, if we write the series of fractions

$$\frac{0}{\frac{1}{2}b} \diagup \frac{y_2}{x_2} \times \frac{y_2'}{x_2'} \diagdown \frac{0}{\frac{1}{2}b},$$

and add the products of the quantities that are connected by full lines, the resulting sum will be the area desired.

To find the area $enmk$ of the earth section, let c be the width of the shelf ea or bn. Then,

$$\begin{aligned}\text{area } enmk &= \text{trapezoid } kq - \text{trapezoid } kl - \text{trapezoid } ln \\ &\qquad - \text{trapezoid } nq \\ &= \tfrac{1}{2}(y_1+y_1')(x_1+x_1') - \tfrac{1}{2}(y_1+y_2)(x_1-x_2-c) \\ &\quad - \tfrac{1}{2}(y_2+y_2')(x_2+x_2'+2c) - \tfrac{1}{2}(y_1'+y_2')(x_1'-x_2'-c) \\ &= \tfrac{1}{2}(x_1'y_1 + y_1x_2 + x_2'y_1' + x_1y_1' - x_1y_2 \\ &\quad - x_2y_2' - y_2x_2' - x_1'y_2') + \tfrac{1}{2}c(y_1 - y_2 + y_1' - y_2) \qquad (2)\end{aligned}$$

The expression in the first parenthesis is most easily formed by writing the series

$$\frac{0}{x_1'} \diagup \frac{y_1}{x_1} \times \frac{y_2}{x_2} \times \frac{y_2'}{x_2'} \times \frac{y_1'}{x_1'} \diagdown \frac{0}{x_1}$$

and forming the products indicated, giving the plus sign to those connected by the full lines, and the minus sign to those connected by the dotted lines, as explained in Art. **26.**

When the areas of the end sections of the rock and earth cuts have been found by formulas **1** and **2**, respectively, the volumes V_1 are obtained by formula **2**, Art. **21.** The prismoidal correction is then computed by formula **2**, Art. **24.** In applying this formula to the rock section, we assume

$$d = v\,t \text{ (Fig. 11)} = \tfrac{1}{2}(y_2 + y_2');$$

in applying it to the earth section, we assume

$$d = s\,t = \tfrac{1}{2}(y_1 + y_1') - v\,t$$

Example.—From the following notes, which contain the full measurement of a portion of a completed cut, compute the volume of rock and that of earth between Sta. 362 and Sta. 363, if the roadbed is 20 feet wide, and the shelf $a\,e = b\,n$ (Fig. 11) is 1 foot wide.

Station	Left		Right	
	Earth	Rock	Rock	Earth
363	$\frac{C\ 8.0}{14.0}$	$\frac{C\ 6.8}{11.4}$	$\frac{C\ 7.2}{12.2}$	$\frac{C\ 10.5}{16.0}$
362	$\frac{C\ 15.0}{18.0}$	$\frac{C\ 12.2}{14.0}$	$\frac{C\ 13.0}{15.0}$	$\frac{C\ 18.0}{20.0}$
361	$\frac{C\ 8.0}{18.4}$	$\frac{C\ 2.0}{11.0}$	$\frac{C\ 3.6}{11.0}$	$\frac{C\ 6.0}{15.1}$

Solution.—To compute the rock area at Sta. 362, we write the series

$$\frac{0}{10} \diagup \frac{12.2}{14.0} \times \frac{13.0}{15.0} \diagdown \frac{0}{10}$$

From this we have

$$\text{area} = \tfrac{1}{2} \times (122 + 182 + 130 + 183) = 308.5 \text{ sq. ft.}$$

Similarly, at Sta. 363, we have the series

$$\frac{0}{10} \diagup \frac{6.8}{11.4} \times \frac{7.2}{12.2} \diagdown \frac{0}{10}$$

from which

$$\text{area} = \tfrac{1}{2} \times (68 + 82 + 72 + 83) = 152.5 \text{ sq. ft.}$$

Therefore, for the rock,

$$V_1 = \frac{100}{2 \times 27} \times (308.5 + 152.5) = 854 \text{ cu. yd.}$$

To find the area of the earth section at Sta. 362, we write the series

$$\frac{0}{20.0} \diagup \frac{15.0}{18.0} \times \frac{12.2}{14.0} \times \frac{13.0}{15.0} \times \frac{18.0}{20.0} \diagdown \frac{0}{18.0}$$

from which the partial area is 129.7 sq. ft. To this must be added the second term of formula **2**, or

$\frac{1}{2} c\,(y_1 - y_2 + y_1' - y_2') = \frac{1}{2} \times 1 \times (15 - 12.2 + 18 - 13) = 3.9$ sq. ft.

The total area of the earth section at Sta. 362 is, therefore, $129.7 + 3.9 = 133.6$ sq. ft.

To find the area of the earth section at Sta. 363, we write the series

$$\frac{0}{16.0} \diagup \frac{8.0}{14.0} \times \frac{6.8}{11.4} \times \frac{7.2}{12.2} \times \frac{10.5}{16.0} \diagdown \frac{0}{14.0}$$

from which the partial area is 59.4 sq. ft. The term

$\frac{1}{2} c\,(y_1 - y_2 + y_1' - y_2') = \frac{1}{2} \times 1 \times (8 - 6.8 + 10.5 - 7.2) = 2.3$ sq. ft.

Therefore, the total area is $59.4 + 2.3 = 61.7$ sq. ft. Therefore, for the earth,

$$V_1 = \frac{100}{2 \times 27} \times (133.6 + 61.7) = 362 \text{ cu. yd.}$$

To apply the prismoidal correction, we have, for the rock,

$$\begin{aligned} w &= 14.0 + 15.0 = 29.0 \\ w' &= 11.4 + 12.2 = 23.6 \\ d &= \tfrac{1}{2} \times (12.2 + 13.0) = 12.6 \\ d' &= \tfrac{1}{2} \times (6.8 + 7.2) = 7.0 \end{aligned}$$

Therefore, by formula **2**, Art. **24**,

$$C = \frac{100}{12 \times 27} \times (29.0 - 23.6) \times (7.0 - 12.6) = -9 \text{ cu. yd.}$$

Therefore, for the rock,

$$V = 854 - 9 = 845 \text{ cu. yd.} \quad \text{Ans.}$$

In the earth prismoid, we have

$$\begin{aligned} w &= 18.0 + 20.0 = 38.0 \\ w' &= 14.0 + 16.0 = 30.0 \\ d &= \tfrac{1}{2} \times (15.0 + 18.0) - 12.6 = 3.9 \\ d' &= \tfrac{1}{2} \times (8.0 + 10.5) - 7.0 = 2.3 \end{aligned}$$

Therefore, by formula **2**, Art. **24**,

$$C = \frac{100}{12 \times 27} \times (38.0 - 30.0) \times (2.3 - 3.9) = -4 \text{ cu. yd}$$

Therefore, for the earth,

$$V = 362 - 4 = 358 \text{ cu. yd.} \quad \text{Ans.}$$

33. Borrow Pits.—The name **borrow pit** is applied to an excavation made solely for the purpose of obtaining material with which to make a fill. Sometimes, a borrow pit

is made by widening a cut, as illustrated in Fig. 12, with the idea that the added width, properly graded beside the regular roadbed, may ultimately prove of use as a place for side

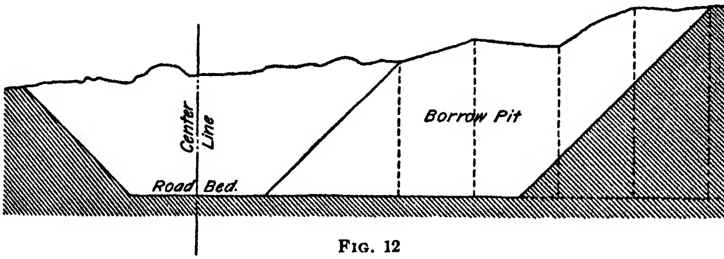


FIG. 12

tracks. In any case, since payment for earthwork is invariably made on the basis of the amount of earth excavated, the excavation is made on regular lines, so that it may be readily measured. Cross-sections of the borrow pits should

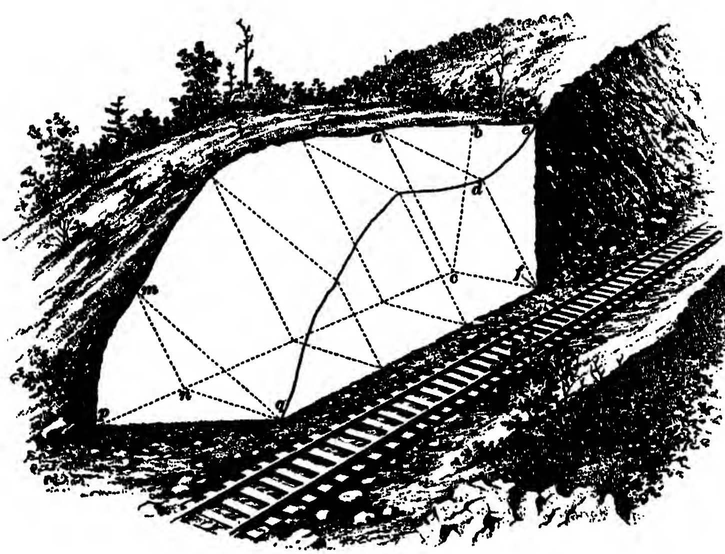


FIG. 13

be made at regular intervals, and the amount excavated should be computed by the method of average end areas, applying the prismoidal correction when necessary. In

Fig. 13 is given the perspective view of a cut with a borrow pit adjoining it, the borrow pit being made by widening the cut. The cross-sections that would be taken are indicated by the dotted lines. It should be noted that at one end the borrow pit runs to the natural end of the cut, and the terminal solid at this end is the pyramid *m n p q*. At the other end, the terminal solid is the wedge *a b c d e f*, but this occurs because the cut has been left with proper slopes. The volumes of these terminal pyramids and wedges are best obtained by taking cross-sections at their bases *m n q* and *a c f d*, and then computing their volumes by the regular rules of geometry.

34. Allowance for Ditches.—In all the computations of volumes described in the preceding articles, the sections for cuts have been taken as the figures *a c e b*, Fig. 2, and for fill as the figures *a c e b*, Fig. 1. As explained in Art. **12**, however, there will always be the two ditches *a* and *c*, Fig. 2, to be allowed for in cuts, and usually the extra ditch *b*, Fig. 2; while sometimes the ditch *e*, Fig. 1, is added to fills. The areas of the end sections in cuts may be increased by the area of the ditches; and the volumes computed by formula **2**, Art. **21**, and formula **2**, Art. **25**; but it is generally more convenient to compute the volume of the ditches separately, since each ditch is a prism.

If A is the area, in square feet, of a cross-section of a ditch, and l is the length of the ditch, in feet, the volume V_d, in cubic yards, is given by the formula

$$V_d = \frac{A\,l}{27}$$

The material excavated from the ditches *a* and *c*, Fig. 2, is available for embankment, but that excavated from the ditch *b* is usually piled on the ground between the ditch and the point *b*.

EXAMPLE.—If the two ditches *a* and *c*, Fig. 2, are 4 feet wide at the top, 1 foot wide at the bottom, and 2 feet deep, what is the additional excavation required for each 100 feet of cut on account of these ditches?

Solution.—The end section of each ditch is a trapezoid whose bases are 4 ft. and 1 ft., respectively, and whose altitude is 2 ft. Therefore,

$$A = \tfrac{1}{2} \times (4 + 1) \times 2 = 5 \text{ sq. ft., and } V_d = \frac{5 \times 100}{27} = 18.5 \text{ cu. yd.}$$

Since there are two ditches, the volume obtained for the prismoid between any two successive full stations in cuts must be increased by

$$2 \times 18.5 = 37 \text{ cu. yd. Ans.}$$

CORRECTION FOR CURVATURE: GENERAL CASE

35. Eccentricity of a Cross-Section.—All the previous calculations have been made on the assumption that the prismoid has a straight axis and that the end planes are parallel to each other. A large proportion of railroad track is curved, and, since the successive cross-sections of the roadbed are perpendicular to the center line of the road, they are not

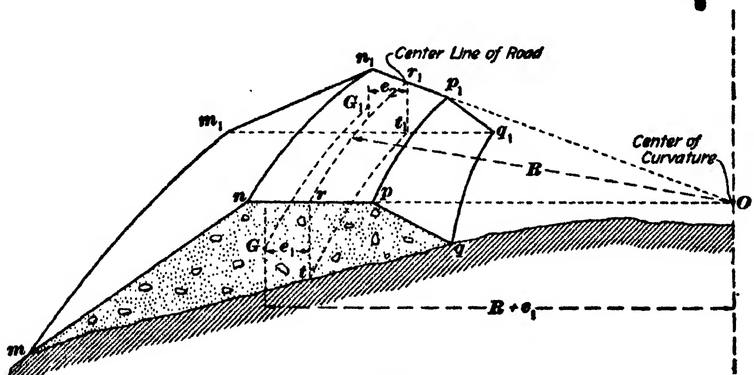


Fig. 14

parallel to each other. In Fig. 14, let A_1 be the area of the cross-section $m\,n\,p\,q$, and A_2 the area of the cross-section $m_1\,n_1\,p_1\,q_1$. Let $r\,r_1$ be the curved center line of the roadbed, and O the center of this circular curve. Let G be the center of gravity of the section $m\,n\,p\,q$, and e_1 the horizontal distance from G to the center of the roadbed. Similarly, let G_1 be the center of gravity of the section $m_1\,n_1\,p_1\,q_1$, and e_2 the horizontal distance from G_1 to the center of the roadbed. The horizontal distance from the center of gravity of any section to the center of the roadbed is called the

eccentricity of the section. Thus, e_1 is the eccentricity of the section $mnpq$, and e_2 is the eccentricity of the section $m_1n_1p_1q_1$.

36. Curvature Correction.—It may be shown by advanced mathematics that the true volume of the curved solid bounded by the sections $mnpq$, $m_1n_1p_1q_1$, Fig. 14, is *greater* than the volume computed as if the track were straight, whenever G and G_1 lie on the *outside* of the center of the roadbed, as shown in Fig. 14, and that, when G and G_1 line on the *inside* of the curved track, the volume is *less* than the volume computed as if the track were straight. The difference between the actual volume and the volume obtained by applying the prismoidal formula is called the **correction for curvature.**

Let V_c = volume of curved solid;

V = volume computed by methods already given, assuming track to be straight;

R = radius Or of center line of roadbed, Fig. 14;

C_c = correction for curvature;

l = distance between end sections measured along center line.

Then, as can be shown by advanced mathematics,

$$C_c = \frac{l}{2R}(A_1e_1 + A_2e_2)$$

If the centers of gravity of the end sections lie on the *outside* of the curved center line of the roadbed, V_c is *greater* than V. If the centers of gravity of the end sections lie on the *inside* of the curved center line of the roadbed, V_c is less than V.

The expression for C_c shows that the larger the eccentricities of the end sections, the larger C_c will be, and that, if the radius of the curve is very large, C_c will be very small. For curves of very large radius, the correction is usually so small that it may be neglected. When the area of that part $rpqt$ of the end section that lies on the inside of the center of the track is approximately equal to the portion of the area $rtmn$ lying outside of the center, the eccentricity

is small, and the correction may usually be neglected, even with curves of short radii. But when the eccentricity is large (as is usually the case in side-hill work), the curvature correction may be a very considerable percentage of the volume, and should not be neglected, especially if the radius of the curve is small.

37. Eccentricity of the Center of Gravity.—The eccentricity being the distance of the center of gravity of the section from a vertical axis through the center of the track, it is found by the method explained in *Analytic Statics*, Part 2, for finding the coordinates of the center of gravity of any plane figure. The section is divided into separate parts, usually triangles, whose centers of gravity can be easily determined. The area of each part is multiplied by the distance of its center of gravity from the axis; the products are added algebraically, and the result is divided by the total area of the section. The quotient is the required eccentricity. It should be borne in mind that, if distances measured from the axis in one direction are treated as positive, those measured in the opposite direction should be treated as negative. The summation of the products is always an algebraic summation. The side of the axis that has the numerically larger products is the side on which the true center of gravity lies.

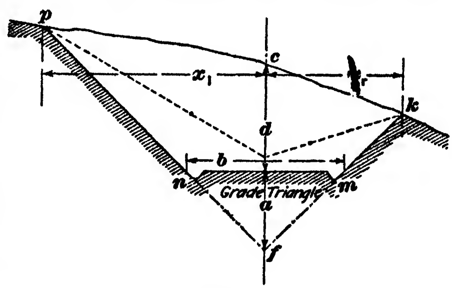


FIG. 15

Fig. 15 represents an ordinary three-level section. If the grade triangle is included, the section may be divided into two triangles pfc and cfk lying on opposite sides of the center line cf. The center of gravity of any triangle is always found on the line joining any vertex with the middle of the opposite side, at one-third of the distance from that side to that vertex. In this case, the perpendicular distance

of the center of gravity of the triangle cpf from the axis cf is evidently one-third of x_l. The area of that triangle is $\frac{1}{2}(a+d)x_l$, and the product of the area and the distance of the center of gravity from the chosen axis is $\frac{(a+d)x_l}{2} \times \frac{x_l}{3}$. Similarly, the distance of the center of gravity of the triangle ckf from the axis is $\frac{x_r}{3}$, and the product of the area by that distance is an expression similar to that already given, and with a minus sign, since the triangle is on the opposite side of the axis. Then, for the eccentricity e, we have,

$$e = \frac{\frac{(a+d)x_l}{2} \times \frac{x_l}{3} - \frac{(a+d)x_r}{2} \times \frac{x_r}{3}}{\frac{(a+d)x_l}{2} + \frac{(a+d)x_r}{2}}$$

$$= \frac{1}{3} \times \frac{x_l^2 - x_r^2}{x_l + x_r} = \frac{1}{3}(x_l - x_r)$$

The value of e given by this formula is the eccentricity of the whole triangle pfk. The eccentricity of the actual section $pnmk$ is somewhat greater than this; in other words, the center of gravity of the actual section is farther from the center line cf than the center of gravity of the actual section and the grade triangle taken together. This is evident, since the center of gravity of the grade triangle lies on the axis cf.

Since the values of e computed by the foregoing formula are too small, these values, when substituted in the formula of Art. **36**, will give too small a value for the curvature correction. It is found practically that this error can be almost exactly counterbalanced by increasing the end areas A_1 and A_2 in this formula by the area of the grade triangle nfm.

38. Another Expression for the Curvature Correction.—If we denote by x_{l1} and x_{r1}, x_{l2} and x_{r2} the values of x_l and x_r, respectively, at two successive sections, and

denote the area of the grade triangle by T, we shall have, from the formula in Art. **37**,

$$e_1 = \tfrac{1}{3}(x_{l1} - x_{r1})$$
$$e_2 = \tfrac{1}{3}(x_{l2} - x_{r2})$$

Substituting these values of e_1 and e_2 in the formula of Art. **36**, and replacing A_1 by $A_1 + T$ and A_2 by $A_2 + T$, we obtain

$$C_c = \frac{l}{6R}[(A_1 + T)(x_{l1} - x_{r1}) + (A_2 + T)(x_{l2} - x_{r2})] \quad \textbf{(1)}$$

It will be observed that this formula would give an exactly correct value of C_c if the cross-sections were the triangles pfk, Fig. 15. Since the true sections are not triangles, the application of the formula introduces two errors: first, the resulting values of the areas $A_1 + T$ and $A_2 + T$ are too great; and, second, the values of the eccentricities e_1 and e_2 are too small. These two errors very nearly neutralize each other. It is not difficult to obtain the true values of e_1 and e_2 for the actual sections $mnpq$, by dividing these sections into triangles; but the resulting equation is not only too long to be of practical value, but in any application it would also be found to give a value of C_c differing from that obtained by the foregoing formula by only a fraction of a cubic yard. Such an error is of no consequence in earthwork computations.

For the purposes of computation, it is convenient to write formula **1** in the following form, the correction being expressed in cubic yards:

$$C_c = \frac{1}{3R}\left[\left(\frac{l}{2\times 27}\times A_1 + \frac{l}{2\times 27}\times T\right)(x_{l1} - x_{r1}) + \left(\frac{l}{2\times 27}\times A_2 + \frac{l}{2\times 27}\times T\right)(x_{l2} - x_{r2})\right] \quad \textbf{(2)}$$

EXAMPLE 1.—In the example of Art. **25**, to find the correction for curvature between Sta. 22 and Sta. 23 if the curve is a 7° curve to the right.

SOLUTION.—At Sta. 22, $x_{l1} = 16.1$, $x_{r1} = 30.2$, and hence $x_{l1} - x_{r1} = 16.1 - 30.2 = -14.1$. At Sta. 23, $x_{l2} = 18.2$, $x_{r2} = 31.4$, and hence $x_{l2} - x_{r2} = 18.2 - 31.4 = -13.2$. The values of $\frac{100}{2\times 27}\times A_1 + \frac{100}{2\times 27}\times T$

and $\frac{100}{2 \times 27} \times A_2 + \frac{100}{2 \times 27} \times T$ have been computed and tabulated in column 7 (*a*) of the table given in Art. **25**. Thus,

$$\frac{100}{2 \times 27} \times A_1 + \frac{100}{2 \times 27} \times T = 579,$$

and

$$\frac{100}{2 \times 27} \times A_2 + \frac{100}{2 \times 27} \times T = 767$$

Substituting all of these values in formula **2**, and also the value $R = 819$ ft. for a 7° curve, we obtain,

$$C_c = \frac{1}{3 \times 819} \times (579 \times -14.1 + 767 \times -13.2) = -7 \text{ cu. yd.}$$

Since x_{l_1} and x_{l_2} are smaller, respectively, than x_{r_1} and x_{r_2}, the centers of gravity of the sections lie on the right of the center line of the roadbed; since the curve turns to the right, these points therefore lie inside of the center line, and the actual volume V_c is less than V (Art. **36**). We therefore have, since the volume computed by the prismoidal formula is 1,048 − 3 = 1,045 cu. yd. (Art. **25**),

$$V_c = 1{,}045 - 7 = 1{,}038 \text{ cu. yd. Ans.}$$

EXAMPLE 2.—To find the correction for curvature between Sta. 24 and Sta. 24 + 35 in the example of Art. **25**, if the curve is a 7° curve to the right.

SOLUTION.—At Sta. 24, $x_{l_1} - x_{r_1} = 24.2 - 39.8 = -15.6$; and at Sta. 24 + 35, $x_{l_2} - x_{r_2} = 19.9 - 28.1 = -8.2$. The values of $\frac{100}{2 \times 27} \times A_1 + \frac{100}{2 \times 27} \times T$ and $\frac{100}{2 \times 27} \times A_2 + \frac{100}{2 \times 27} \times T$ given in column 7 (*a*) of the table must be multiplied by $\frac{35}{100}$, since the distance between the sections is but 35 ft. Then,

$$C_c = \frac{1}{3 \times 819} \times \left(\tfrac{35}{100} \times 1{,}132 \times -15.6 + \tfrac{35}{100} \times 684 \times -8.2\right)$$
$$= -3 \text{ cu. yd.}$$

As in example 1, the actual volume is less than the volume V computed by the prismoidal formula. From Art. **25**, $V = 531 - 6 = 525$ cu. yd.; hence,

$$V_c = 525 - 3 = 522 \text{ cu. yd. Ans.}$$

EXAMPLES FOR PRACTICE

1. In the preceding examples of this article, find the correction for curvature and the volume between Sta. 23 and Sta. 24.

Ans. $C_c = -11$; $V_c = 1{,}579$ cu. yd.

2. In the preceding examples of this article, find the correction for curvature and the volume between Sta. 24 + 35 and Sta. 25.

Ans. $C_c = -2$; $V_c = 403$ cu. yd.

CORRECTION FOR CURVATURE: SIDE-HILL WORK

39. Importance of Curvature Correction in This Case.—Side-hill sections usually have their centers of gravity at such distances from the center of the road that the correction for curvature is a large percentage of the total volume, even when that volume is small. Therefore, in side-hill work, it is nearly always necessary to compute the curvature correction. It will always be sufficiently accurate, *for the purpose of this correction*, to consider that the side-hill section is a triangle. By this means, the calculation of the position of the center of gravity is readily performed. The curvature correction for the cut and that for the fill must be computed separately.

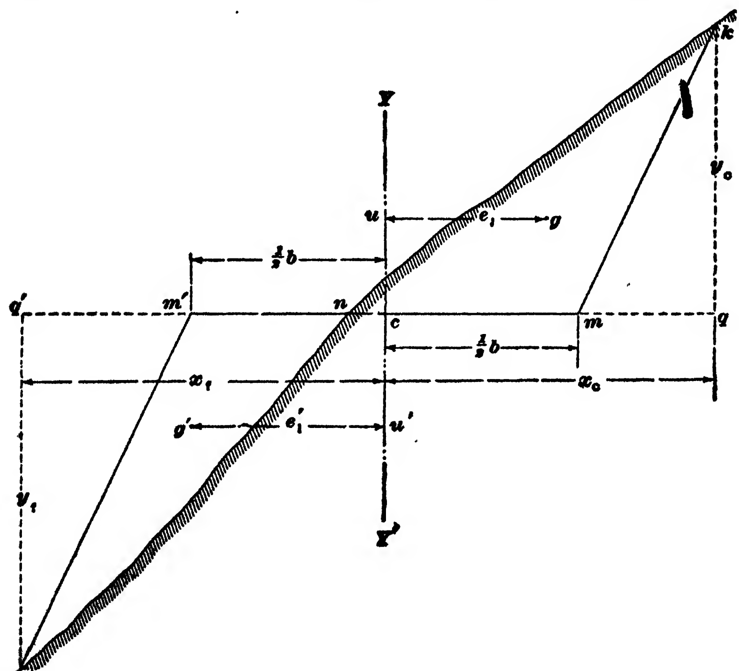


FIG. 16

40. Curvature Correction for the Cut.—In computing the curvature correction for a cut, it is necessary to distinguish two cases, as follows:

Case I.—*The center stake lies in the cut.* In Fig. 16, let the center stake c lie in the cut $k\,n\,m$. Let $c\,q = x_c$, and $q\,k = y_c$. As usual, the width of subgrade is denoted by b; but it should be observed that the value of b, and therefore of $\frac{1}{2}b$, is not the same for cuts as for fills. Let g be the center of gravity of the triangle $m\,n\,k$, and e_1 the eccentricity $g\,u$. As shown in *Analytic Statics*, Part **2**, if the distances of the vertexes of a triangle from a line are denoted by z_1, z_2, and z_3, the distance z_g of the center of gravity of the triangle from the same line is given by the formula

$$z_g = \frac{1}{3}(z_1 + z_2 + z_3)$$

it being understood that the addition is algebraic, and that distances on opposite sides of the line of reference must have

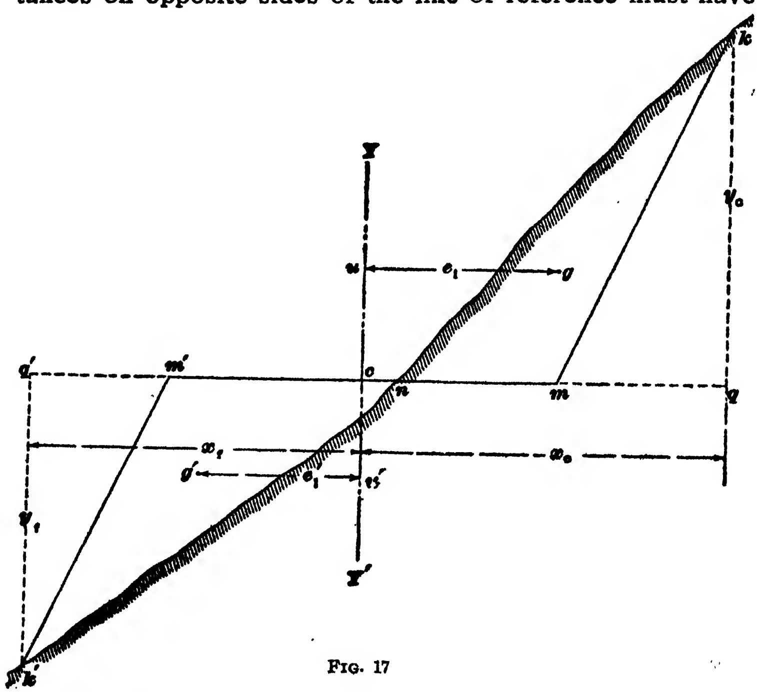


FIG. 17

opposite signs. Applying this formula to the triangle $m\,n\,k$ considering distances to the right of $Y'\,Y$ as positive, we have

$$e_1 = \frac{1}{3}(c\,q + c\,m - c\,n)$$

that is, $$e_1 = \frac{1}{3}(x_c + \frac{1}{2}b - n\,c) \qquad \textbf{(1)}$$

If A_1 = area $m n k$, we have

$$A_1 = \tfrac{1}{2} m n \times q k = \tfrac{1}{2}(n c + \tfrac{1}{2} b) \times y_c \qquad \textbf{(2)}$$

Formulas **1** and **2** give the values of A and e to be substituted in the formula of Art. **36**, in order to obtain the correction for curvature.

Case II.—*The center stake lies in the fill.* From Fig. 17, we have, since here all the vertexes are on the right of $Y' Y$,

$$e_1 = \tfrac{1}{3}(x_c + \tfrac{1}{2} b + c n) \qquad \textbf{(3)}$$

Also, $$A_1 = \tfrac{1}{2} m n \times q k = \tfrac{1}{2}(\tfrac{1}{2} b - c n) y_c \qquad \textbf{(4)}$$

EXAMPLE.—If the curve to which the following notes refer is a 9° curve to the right, what is the correction for curvature for the cut between Sta. 32 and Sta. 33, the roadbed being 24 feet wide in cuts and 16 feet wide in fills?

Station	Center Depth	Left		Right	
33	F 1.3	$\frac{\text{F } 18.8}{36.2}$		$\frac{0}{3.4}$	$\frac{\text{C } 17.1}{37.7}$
32	C 2.0	$\frac{\text{F } 15.0}{30.5}$	$\frac{0}{4.4}$		$\frac{\text{C } 14.9}{34.4}$

SOLUTION.—At Sta. 32, there is a cut at the center stake. Formulas **1** and **2** are therefore applied. We have, from the notes, $x_c = 34.4$, and $c n = 4.4$; also, $\frac{1}{2} b = \frac{24}{2} = 12$. Therefore, by formula **1**,

$$e_1 = \tfrac{1}{3} \times (34.4 + 12 - 4.4) = 14 \text{ ft.}$$

By formula **2**, $A_1 = \frac{1}{2} \times (4.4 + 12) \times 14.9$ sq. ft.

At Sta. 33, there is a fill at the center stake; formulas **3** and **4** are therefore applied. At this station, $x_c = 37.7$, $\frac{1}{2} b = 12.0$, and $c n = 3.4$. Therefore, by formula **3**,

$$e_2 = \tfrac{1}{3} \times (37.7 + 12.0 + 3.4) = 17.7 \text{ ft.}$$

By formula **4**, $A_2 = \frac{1}{2} \times (12 - 3.4) \times 17.1$ sq. ft.

Substituting these values, and also $l = 100$ and $R = 637$ in formula of Art. **36**, and dividing by 27 to reduce the result to cubic yards,

$$C_c = \frac{100}{2 \times 27 \times 637} \times (\tfrac{1}{2} \times 16.4 \times 14.9 \times 14.0 + \tfrac{1}{2} \times 8.6 \times 17.1 \times 17.7)$$
$$= 9 \text{ cu. yd.}$$

Since the curve turns to the right, the center of gravity evidently lies inside of the center of the roadbed. Hence, by Art. **36**, the volume obtained by applying the prismoidal formula should be *diminished* by 9 cu. yd., in order to obtain the actual volume.

41. Curvature Correction for the Fill.—As in the case of the cut, so in computing the curvature correction for the fill, two cases are distinguished:

Case I.—*The center stake lies in the cut.* If g', Fig. 16, is the center of gravity of the triangle $k'\,m'\,n$, we shall have, denoting $c\,q'$ by x_f,

$$e_1' = g'\,u' = \tfrac{1}{3}\left(x_f + \tfrac{1}{2}\,b + c\,n\right) \qquad (1)$$

If A_1' = area $k'\,m'\,n$, and $k'\,q' = y_f$, then,

$$A_1' = \tfrac{1}{2}\,m'\,n \times k'\,q' = \tfrac{1}{2}\left(\tfrac{1}{2}\,b - c\,n\right)y_f \qquad (2)$$

Case II.—*The center stake lies in the fill.* In Fig. 17, the notation being as before, we have

$$e_1' = g'\,u' = \tfrac{1}{3}\left(x_f + \tfrac{1}{2}\,b - n\,c\right) \qquad (3)$$

If A_1' is the area of the fill triangle, then,

$$A_1' = \tfrac{1}{2}\,m'\,n \times k'\,q' = \tfrac{1}{2}\left(\tfrac{1}{2}\,b + c\,n\right)y_f \qquad (4)$$

EXAMPLE.—To find the correction for curvature for the fill in the example of Art. **40**.

SOLUTION.—For Sta. 32, formulas **1** and **2** must be used. From the notes, $x_f = 30.5$, $\tfrac{1}{2}b = 8$, and $n\,c = 4.4$. Therefore,

$$e_1' = \tfrac{1}{3} \times (30.5 + 8.0 + 4.4) = 14.3$$

$$A_1' = \tfrac{1}{2} \times (8.0 - 4.4) \times 15.0 = \tfrac{1}{2} \times 3.6 \times 15.0$$

For Sta. 33, formulas **3** and **4** must be used. Here, $x_f = 36.2$, $\tfrac{1}{2}b = 8$, and $c\,n = 3.4$; therefore,

$$e_2' = \tfrac{1}{3} \times (36.2 + 8.0 - 3.4) = 13.6$$

$$A_2' = \tfrac{1}{2} \times (8 + 3.4) \times 18.8 = \tfrac{1}{2} \times 11.4 \times 18.8$$

Hence,

$$C_c = \frac{100}{2 \times 27 \times 637} \times \left(\tfrac{1}{2} \times 3.6 \times 15.0 \times 14.3 + \tfrac{1}{2} \times 11.4 \times 18.8 \times 13.6\right)$$

$$= 5 \text{ cu. yd.}$$

Since the center of gravity of the fill evidently lies outside of the center line of the curve, the volume computed by the prismoidal formula should be increased by 5 cu. yd., in order to obtain the actual volume.

EXAMPLES FOR PRACTICE

1. The following notes apply to a 10° curve to the left. The roadbed is 24 feet wide in the cuts, and 16 feet wide in the fills. Find the correction for curvature for the cut between Sta. 161 and Sta. 162.

Station	Center Depth	Left		Right	
162	C 3.0	$\frac{\text{F } 25.5}{46.3}$	$\frac{0}{1.5}$		$\frac{\text{C } 22.4}{45.6}$
161	F 2.4	$\frac{\text{F } 28.5}{50.8}$		$\frac{0}{6.3}$	$\frac{\text{C } 12.2}{30.3}$

Ans. C_c = 11 cu. yd. (to be added)

2. Find the correction for curvature for the fill in the preceding example. Ans. $C_{c'}$ = 16 cu. yd. (to be subtracted)

3. If the roadbed to which the following notes refer is 20 feet wide in the cuts, find the correction for curvature for the cut between Sta. 22 + 40 and Sta. 23, the curve being a 10° curve to the left.

Station	Center Depth	Left		Right	
23	C 6.0	$\frac{\text{F } 18.9}{36.4}$	$\frac{0}{6.0}$		$\frac{\text{C } 20.0}{40.0}$
22 + 40	F 0.8	$\frac{\text{F } 18.0}{35.0}$		$\frac{0}{2.0}$	$\frac{\text{C } 18.0}{37.0}$

Ans. C_c = 4.5 cu. yd. (to be added)

SHRINKAGE OF EARTHWORK

42. It is usually observed that, when earth is excavated and formed into an embankment, the volume of the embankment is at first greater than that of the original excavation, but, after some time, the embankment shrinks to a volume less than that of the original excavation. This **shrinkage** generally amounts, on an average, to about 10 per cent., although in the case of very loose vegetable soil it may amount to as much as 25 per cent. Table I contains in the second column the approximate number of cubic yards of

embankment that can be formed from 1,000 cubic yards of excavation. In the third column is given the number of cubic yards of excavation required for each 1,000 cubic yards of embankment, and in the fourth column is given the per cent. of shrinkage for the various kinds of soils.

TABLE I

SHRINKAGE OF EARTHWORK

Character of Material	Embankment Obtained From 1,000 Cubic Yards of Excavation Cubic Yards	Excavation Required for 1,000 Cubic Yards of Embankment Cubic Yards	Shrinkage Per Cent.
Sand and gravel	920	1,087	8
Clay	900	1,111	10
Loam	880	1,136	12
Wet soil	850	1,200	15

EXAMPLE 1.—The volume of a cut through clay soil is 1,630 cubic yards. How many cubic yards will be contained in an embankment made from this material?

SOLUTION 1.—Since, from Table I, 1,000 cu. yd. of excavation will form only 900 cu. yd. of embankment, the desired result will be

$$\tfrac{900}{1000} \times 1{,}630 = 1{,}467 \text{ cu. yd.} \quad \text{Ans.}$$

SOLUTION 2.—Since, from Table I, the shrinkage is 10 per cent., the shrinkage will be 10 per cent. of 1,630 cu. yd., or 163 cu. yd. Therefore, the volume of the embankment will be

$$1{,}630 - 163 = 1{,}467 \text{ cu. yd.} \quad \text{Ans.}$$

EXAMPLE 2.—How many cubic yards of excavation in gravel are required to form an embankment of 2,200 cubic yards?

SOLUTION.—Since, from Table I, each 1,000 cu. yd. of embankment will require 1,087 cu. yd. of excavation, the desired result will be

$$\tfrac{1087}{1000} \times 2{,}200 = 2{,}391 \text{ cu. yd.} \quad \text{Ans.}$$

43. Growth of Rock.—When a rock excavation is formed into an embankment, it will have a volume from 40 to 80 per cent. larger than its original volume in the cut, and there will be practically no subsequent settling of the embankment. This increase in volume is called the **growth** of rock.

Table II shows the approximate number of cubic yards of embankment that can be formed from 1,000 cubic yards of excavation, the number of cubic yards of excavation required for 1,000 cubic yards of embankment, and the per cent. of growth for the various sizes of hard rock.

TABLE II

GROWTH OF ROCK

Character of Material	Embankment Obtained From 1,000 Cubic Yards of Excavation Cubic Yards	Excavation Required for 1,000 Cubic Yards of Embankment Cubic Yards	Growth Per Cent.
Hard rock, large fragments .	1,600	625	60
Hard rock, medium fragments	1,700	587	70
Hard rock, small fragments .	1,800	556	80

EXAMPLE.—How many cubic yards of embankment will be obtained from a rock cut 4,500 cubic yards, if the rock is broken into small fragments?

SOLUTION 1.—Since, from Table II, 1,000 cu. yd. of cut will form 1,800 cu. yd. of fill, the desired number will be

$$\frac{1800}{1000} \times 4{,}500 = 8{,}100 \text{ cu. yd.} \quad \text{Ans.}$$

SOLUTION 2.—Since, from Table II, the growth is 80 per cent., the growth will be 80 per cent. of 4,500 or 3,600; the desired number is, therefore,

$$4{,}500 + 3{,}600 = 8{,}100 \text{ cu. yd.} \quad \text{Ans.}$$

44. The numbers in Table II are necessarily only rough approximations, but the table will give fairly accurate results if the rock is hard rock. If the rock is of a soft earthy nature, or is what is known as *rotten rock*, the percentage of enlargement after excavation is less, and there is more or less subsequent shrinkage. The transition from hard rock to soft earth is so gradual that the engineer must estimate to the best of his ability between the extremes of a 60- to 80-per-cent. growth in an embankment formed from solid

rock to a 10-per-cent. or possibly a 25-per-cent. shrinkage in the case of very soft vegetable soil. Experience alone will determine what value should be chosen within this large range of extreme values. It should be kept in mind that a very soft vegetable soil or a material resembling quicksand is not suitable as a material for embankments, and, therefore, when such material is excavated, it is often better to discard it, and, if necessary, to borrow material with which to form adjacent embankments.

On account of these uncertainties in shrinkage and growth, it is the invariable custom to compute all earthwork and rockwork by measuring the volume of the original excavation, whether it is a cut or a borrow pit. The contractor is then required to dispose of all excavated material where directed, subject to an allowance for haul, as described later, and he need not concern himself with the question of how much embankment will be made from the excavated material.

EXAMPLES FOR PRACTICE

1. Find the amount of embankment that can be formed from a cut of 3,200 cubic yards in loam. Ans. 2,816 cu. yd.

2. Find the amount of embankment that can be formed from a cut of 2,500 cubic yards in hard rock, if the rock is broken into medium-sized fragments. Ans. 4,250 cu. yd.

3. Find the volume required for a borrow pit in sandy soil to furnish 3,590 cubic yards of embankment. Ans. 3,902 cu. yd.

ACCURACY OF EARTHWORK COMPUTATIONS

45. The volumes obtained for earthwork are never more than approximations to the true volumes, and their error frequently amounts to several cubic yards in a prismoid 100 feet long. In cuts, this error is principally caused by the unevenness of the natural surface of the ground between successive cross-sections. The volume computed is that of a prismoid, which is a perfectly regular geometrical solid having straight edges, and the area and shape of any section of which varies uniformly from one base to the other. Evidently, the rough surface of the natural soil never

exactly coincides with one face of any such prismoid; a slight mound or hollow may cause the actual volume to differ by several cubic yards from the computed volume. The accuracy of the computed volumes could be increased by taking cross-sections at very frequent intervals; but, as explained in Art. **20**, the cost of this additional labor usually prevents it. In fills, there is not only the same error arising from the irregularity of the natural surface on which the embankment rests, but there is also a much greater error arising from the uncertainty of the amount of shrinkage that the material of the embankment will undergo.

Since the results of any computation are uncertain to the extent at the very least of 1 or 2 cubic yards per station, the formulas that have been given in the preceding articles can frequently be applied rapidly in an approximate manner. To take a single example, the expression for C_c in the example of Art. **40** is as follows:

$$C_c = \frac{100}{2 \times 27 \times 637} \times (\tfrac{1}{2} \times 16.4 \times 14.9 \times 14 + \tfrac{1}{2} \times 8.6 \times 17.1 \times 17.7)$$

Instead of performing in full the operations indicated, the experienced engineer would probably obtain the value of C_c, mentally, somewhat as follows: 14.9×14 is about 200; 17.1×17.7 is about 300; the parenthesis is therefore about $8\tfrac{1}{4} \times 200 + 4\tfrac{1}{3} \times 300 = 2{,}950$ and C_c is $\frac{50}{27} \times \frac{2950}{637} =$ (about) $2 \times 4\tfrac{1}{2} = 9$ cubic yards.

In obtaining the quantity of earth in small volumes also, such as that of the wedge *abcdef*, Fig. 13, or of the pyramid *mnpq*, Fig. 13, an engineer of experience can, by merely glancing at the excavation on the ground, frequently estimate the volumes very closely.

HAULAGE

46. Limit of Free Haul.—The most variable item in the cost of earthwork, and the one that in some cases is the largest single item, is that which depends on the length of haul—that is, the distance through which excavated material must be hauled or transported. Specifications usually require

that a contractor shall deposit excavated material at any place designated by the engineer, and that his bid per cubic yard shall cover the cost of such haul, provided that the distance does not exceed 800 or perhaps 1,000 feet. This extreme distance is called the **limit of free haul.** At the same time it is specified that, if the haul exceeds this distance, there shall be an extra allowance per cubic yard for each distance of 100 feet that the material may be hauled. The sum of all the products obtained by multiplying each cubic yard of earth by the number of stations that it is hauled beyond the specified limit is called the **overhaul.** It is necessary to devise some practicable method of estimating the length of haul, not only for the sake of computing the extra allowance arising from overhaul, but also so that different plans for the disposal of the material may be readily made and compared, and so that the plan involving the least amount of haulage may be readily determined.

47. Computation of Haulage.—It is evidently impracticable to compute the haul of each individual cartload of earth and to measure its precise volume. Fortunately, this is not necessary. When any given volume of material is to be transported to any given locality, it makes no difference (at least from the theoretical standpoint) how each individual cubic yard of earth may be hauled. The **total haulage** is the sum of all the products obtained by multiplying each volume by the distance through which this volume is hauled. The total haulage is equal to the total number of cubic yards multiplied by the distance between the center of gravity of the original excavation and the center of gravity of the embankment formed by that excavation. This principle makes the computation of haulage comparatively simple.

Fig. 18 shows a profile of the roadbed at the point in which it passes from a cut to a fill. If all the material of the cut is deposited in the position OND, the total haulage will be

$$\text{volume } CMO \times ZZ' = \text{volume } OND \times ZZ',$$

G and G' being, respectively, the centers of gravity of the cut CMO and the embankment ODN.

If the distance CD is less than the limit of free haul, the contractor is entitled to no extra compensation in connection with the above cut. It should be observed also that the contractor is entitled to the benefit of all short hauls; that is, material so moved is not averaged against that which is carried beyond the limit. Therefore, in cuts the material of which is deposited within the specified limit of haul, no computation of haul need be made.

If there is overhaul at any cut, the contractor does not receive extra compensation for that portion of the cut which is not carried beyond the specified limit. Thus, in Fig. 18, if AB is a distance equal to the limit of free haul, and the material AKO is deposited at OLB, it is evident that no extra charge is admissible for this material. But every

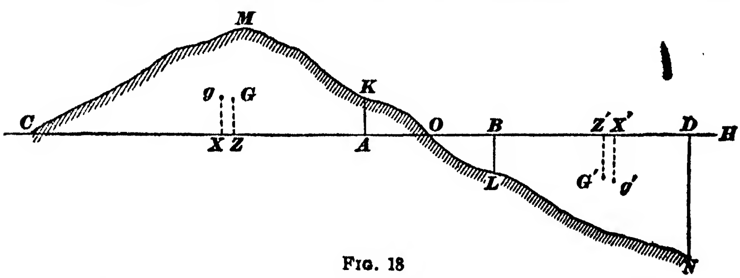


FIG. 18

cubic yard excavated from the left of A and transported to the right of B is overhauled, and, for this, extra compensation must be allowed.

48. The first step in computing the overhaul is to find two points A and B on the profile whose distance apart equals the limit of free haul, and which are so situated that the volume of the cut AKO equals the volume of the fill BOL. This is easily done by trial when the volume of each of the prismoids along CH has been computed. Frequently, it is sufficiently accurate to locate A and B from the profile by shifting these points backwards and forwards until a position is found for which the area KOA is equal to the area BOL.

For moving the material KOA to the position BOL, there is no allowance for overhaul. If g is the center of

gravity of the excavation CKA, and g' that of this material in the embankment $BLND$, and if V is the volume of the cut CKA, then $V \times XX'$ is the haulage of the volume V. But, since this volume must be hauled the length of the free haul AB without extra charge, the overhaul will be

$$V \times XX' - V \times AB = V \times (XX' - AB)$$
$$= V \times XA + V \times X'B$$

The values of $V \times XA$ and $V \times X'B$ are found as follows:

Let v = volume of any prismoid in cut;
a = area of its end section nearest to A;
a' = area of its end section most remote from A;
m = distance from A to middle section of prismoid;
l = length of prismoid, in feet;
x = distance from center of gravity of this prismoid to point A.

Then, as may be proved by the use of advanced mathematics,

$$x = m + \frac{l}{6} \times \frac{a' - a}{a' + a}$$

The overhaul of this prismoid from its position in the cut to the point A will therefore be, since overhaul is reckoned in stations,

$$\frac{vx}{100} = \frac{v}{100}\left(m + \frac{l}{6} \times \frac{a' - a}{a' + a}\right)$$

By this formula, the overhaul for each prismoid of the cut is computed for the transportation of this material to the point A. In an exactly similar manner, the overhaul for the transportation of each prismoid to its position in the fill BLN from the point B is found. The sum of the overhauls for all the prismoids of the cut and fill is the desired total overhaul.

If a part of the cut, for example MZO, is hauled in one direction, and the remainder MZC in the other, the overhaul for each part of the cut must be computed separately.

Example.—In the example of Art. 28, the point A, Fig. 18, is at Sta. 129, the length of free haul is 600 feet, and the notes showing

the volumes and end areas of the prismoids beyond Sta. 135 are as follows:

Station	End Area	Volume (a)	Volume (b)
137	769	1,422	1,918
136	268	496	2,460
135	844	1,564	
			Sum = 4,378

If 1 cent is paid for each cubic yard hauled one station in the overhaul, find the total allowance for overhaul if the shrinkage of the material in embankment is 10 per cent.

SOLUTION.—The foregoing formula must be applied to each of the prismoids.

1. *For the Cut.*—We have the following tabulation of the end areas and volumes; the end areas are the algebraic sums of one-half the plus and minus areas found in the tabulation of Art. 28, and the volumes are obtained by applying the prismoidal correction to the volumes in column 4 (b) of that table.

Station	End Areas	Volume	m	$\frac{l}{6}\left(\frac{a'-a}{a'+a}\right)$	x	$\frac{vx}{100}$
129	368.5	1,195	30	+ 5	35	418
128 + 40	724.8	883	80	− 4	76	671
128	471.9	1,690	150	− 1	149	2,518
127	439.4	1,074	250	− 7	243	2,610
126	157.4					
		Sum = 4,842				Sum = 6,217

The numbers in the fourth column are the distances from the middle sections of the prismoids to the point A, Fig. 18, at Sta. 129, at which point the free haul begins. Thus, the middle section of the prismoid between Sta. 126 and Sta. 127 is at Sta. 126 + 50; the distances from this section to Sta. 129 is $(129 - 126.50) \times 100 = 250$ ft. Similarly, for the prismoid between Sta. 127 and Sta. 128, $m = (129 - 127.50) \times 100 = 150$ ft.

The value of $\frac{l}{6} \times \frac{a' - a}{a' + a}$, for each prismoid, is given in the fifth column. Thus, for the first prismoid,

$$\frac{100}{6} \times \frac{157.4 - 439.4}{157.4 + 439.4} = -7 \text{ ft.}$$

For the second prismoid,

$$\frac{100}{6} \times \frac{439.4 - 471.9}{439.4 + 471.9} = -1 \text{ ft.}$$

and similarly for the others.

The numbers in the sixth column are the sums of the corresponding numbers in the fourth and fifth columns; each of these numbers in the sixth column is the distance from the point A, Fig. 18, to the center of gravity of the corresponding prismoid.

Finally, the overhaul for each prismoid is the product of the volume in the third column by the distance x in the sixth column. These products are written in the seventh column; but, since the distance x is expressed in feet, and the allowance is 1 cent per cubic yard per station, each product is divided by 100 before writing it in the seventh column. The sum of the numbers in the seventh column is 6,217; the overhaul for the cut is therefore the equivalent of 6,217 cu. yd. overhauled one station.

2. *For the Fill.*—The total volume of the cut is 4,842 cu. yd. Since the shrinkage is 10 per cent., the volume of this material when placed in the embankment will be 4,842 − 484 = 4,358 cu. yd. Since the volume of the embankment between Sta. 135 and Sta. 137 is 4,378 cu. yd., the embankment made from the cut practically ends at Sta. 137. Therefore, the point D, Fig. 18, may be taken as Sta. 137.

The computation of overhaul for fill between Sta. 135, or B, Fig. 18, and the center of gravity of each prismoid is now computed exactly as in the case of the cut. The results are shown in the following table:

Station	End Area	Volume	m	$\frac{l}{6} \times \frac{a'-a}{a'+a}$	x	$\frac{v x}{100}$
137	769	1,918	150	+ 8	158	3,030
136	268	2,460	50	− 9	41	1,330
135	844					

Sum = 4,360

The sum of all the values of $\frac{v x}{100}$ is 6,217 + 4,360 = 10,577. This is the equivalent of 10,577 cu. yd. overhauled one station. At the rate of 1 cent per cubic yard per station, the allowance for overhaul will be

$$.01 \times 10{,}577 = \$105.77. \quad \text{Ans.}$$

EXAMPLE FOR PRACTICE

If the cut in the following notes extends from Sta. 64 to Sta. 67, and the fill from Sta. 67 on, and if the point A, Fig. 18, is at Sta. 64, find the allowance for overhaul at the rate of 1 cent per cubic yard per station.

The length of free haul is 600 feet, and the allowance for shrinkage is 10 per cent.

Station	End Area	Volume	
		(a)	(b)
72	89	163	773
71	330	610	1,036
70	235	426	
64	323	586	1,104
63	284	518	900
62	210	382	

Ans. $35.03

GRAPHIC COMPUTATIONS

49. The Mass Diagram and the Mass Curve.—The method described in the preceding article for computing the total haulage and the allowance for overhaul is very accurate and can easily be applied when there are but few cuts and fills at which the question of allowance for overhaul needs to be investigated. But in many cases, and especially in *preliminary estimates* of the cost of earthwork, a graphic method is sufficiently accurate. Such a method is briefly outlined in the present and in the following articles.

Fig. 19 represents a **mass diagram**, which consists of the profile $i' n' j' k'$ of the road drawn to the usual vertical and horizontal scales, the subgrade GR, and the **mass curve** ijk, which is drawn above the profile to the same horizontal scale, in a manner to be described presently. Natural conditions frequently determine with practical certainty that no earth will be hauled beyond certain points, as a river crossing. Beginning at some such point, which will be the point i' in Fig. 19, a table like the one given on page 67 is prepared. The first column contains the station numbers, and the second the number of cubic yards of cut or fill between each station and the station immediately preceding. Cut is here indicated by a plus sign, and fill by a minus sign. Even approximate accuracy requires that shrinkage be allowed for;

the third column therefore contains a statement of the character of all material excavated, and in the fourth column is placed the shrinkage factor for that particular class of material. The fifth column contains the volumes obtained from those in the second column by applying the correction for shrinkage. The sixth column is formed by taking the algebraic sum of all the numbers of cubic yards (as given in

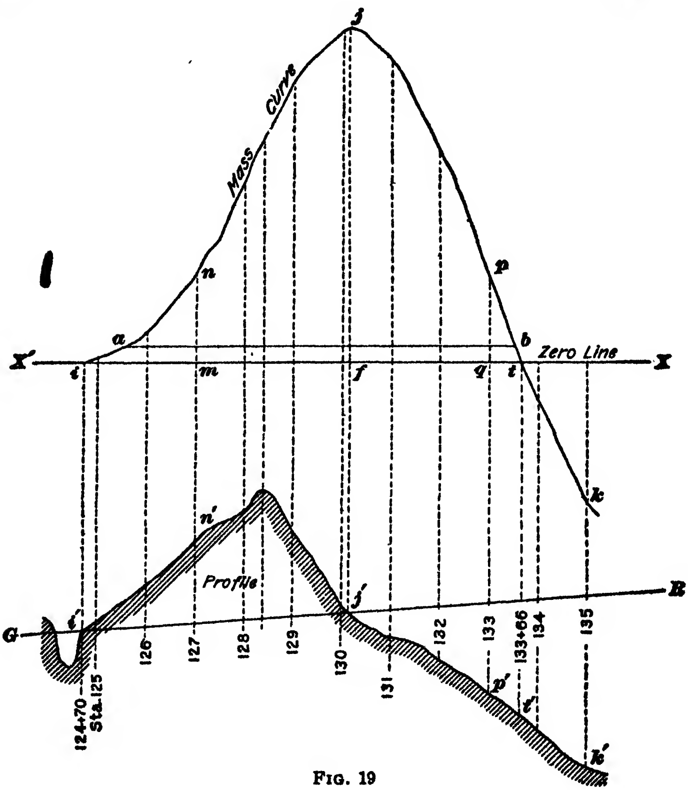


FIG. 19

the fifth column) from the starting point up to the station considered. For example, the number 4,647, given in the sixth column, is the sum of 128, 635, 1,540, and 2,344. The volume − 960, opposite Sta. 131 in the fifth column, means that, between Sta. 130 + 10 and Sta. 131, there was a fill of 960 cubic yards; the number 7,827 in the sixth column is

DETERMINATION OF ORDINATES FOR MASS CURVE

Station	Yards {Cut + / Fill −	Material	Shrinkage Factor Per Cent.	Yards Reduced for Shrinkage	Ordinate to Mass Curve
124 + 70					0
125	+ 142	Gravel and clay	− 10	+ 128	+ 128
126	+ 706	Gravel and clay	− 10	+ 635	+ 763
127	+ 1,711	Gravel and clay	− 10	+ 1,540	+ 2,303
128	+ 2,605	Gravel and clay	− 10	+ 2,344	+ 4,647
+ 40	+ 1,280	Gravel and clay	− 10	+ 1,152	+ 5,799
129	+ 1,688	Gravel and clay	− 10	+ 1,519	+ 7,318
130	+ 1,422	Gravel and clay	− 10	+ 1,280	+ 8,598
+ 10	+ 210	Gravel and clay	− 10	+ 189	+ 8,787
131	− 960			− 960	+ 7,827
132	− 2,340			− 2,340	+ 5,487
133	− 3,285			− 3,285	+ 2,202
134	− 3,328			− 3,328	− 1,126
135	− 2,488			− 2,488	− 3,614

obtained by subtracting from the previous sum total 8,787 the number 960. To obtain the next number 5,487, 2,340 is subtracted from 7,827. When Sta. 134 is reached, these successive subtractions produce a negative result.

50. The **mass curve** *ijk* is constructed by laying off as abscissas the distances from the starting point, in this case *i'*, and as ordinates the corresponding values in the sixth column of the table. The axis of abscissas *X' X*, called the **zero line**, is taken at any convenient distance above the profile; and the ordinates of the curve are obtained by producing upwards the vertical lines of the profile. Thus, for Sta. 127, the vertical line through that station in the profile is produced, and on it is laid off, above *X' X*, the distance *m n* to represent, to any convenient scale, the number 2,303 found in the sixth column of the table horizontally opposite Sta. 127. The ordinates corresponding to negative numbers in the sixth column are laid off below the zero line. The vertical scale chosen depends on the magnitude of the earthwork. It should be as large as practicable, since the accuracy of the results is greater the greater the scale used. For a light cutting, a scale of 1,000 cubic yards per inch may not make the diagram too large; but, as the work becomes heavy, 5,000 or even 10,000 cubic yards per inch might be allowable. The scale chosen in Fig. 19 is 5,000 cubic yards per inch.

51. Properties of the Mass Curve.—By comparing Fig. 19 with the notes from which it was constructed, it will be observed that the ordinate corresponding to any station represents the amount of material that can be utilized for embankment beyond that station. Thus, the ordinate *m n*, corresponding to Sta. 127, represents the total amount of material that can be used for filling anywhere beyond Sta. 127; in this case, this is the same as the total amount excavated up to Sta. 127, since the road up to that station is all in cut, and no part of the excavated material has been used. The ordinates therefore increase up to a station where some of the material excavated begins to be used for embankments;

that is, up to a point where the road changes from cut to fill. That station is j' in Fig. 19; the corresponding ordinate of the curve, which is the maximum ordinate, is fj. This ordinate represents the total amount of material excavated. After passing j', the road is in fill; some of the material excavated is used up, and the ordinates of the mass curve decrease. The ordinate qp, for instance, represents the amount of unused material after the embankment up to p' has been made. The difference between the maximum ordinates fj and qp represents the amount of material used for fill between j' and p'. The mass line crosses the zero line at t, which shows that all the material excavated has been used for fill between j' and t'. Negative ordinates of the curve indicate that more material is required for filling than has been excavated. This material may be obtained from excavation farther along the line.

52. Total Haulage.—The most useful application of the mass curve is to the determination of the total haulage. It can be shown by the use of advanced mathematics that *the total haulage between the stations corresponding to two points where the mass curve crosses the zero line is numerically equal to the area included between the mass curve and the zero line.* Thus, in Fig. 19, the total haulage between i' and t' is numerically equal to the area included between the curve ijt and the zero line it. The **average haulage** is obtained by dividing the total haulage by the total volume of excavated material.

The area of the mass curve can be determined by any of the methods explained in *Plane Trigonometry*, Part 2. Care should be taken to make the proper reduction according to the method and scales used. Haulage is usually expressed by a number of *cubic yards* transported a distance of so many *stations* of 100 *feet*. Therefoie, if the area of the curve in square inches is A, and the vertical scale is v cubic yards to the inch, and the horizontal is h stations to the inch, the actual haulage is Ahv. Usually, it is sufficiently accurate to compute the area by treating the portion between two

consecutive ordinates as a trapezoid, using the trapezoidal rule explained in *Plane Trigonometry*, Part 2. In this case, the actual values of the ordinates, as given by the sixth column of the table in Art. 49, are used, and also the actual values, expressed in stations, of the distances between the ordinates. If this method is followed, no further reduction is necessary.

53. Allowance for Overhaul.—The allowance for overhaul is computed from the mass curve as follows: Draw a line *a b*, Fig. 19, parallel to the zero line, and whose length is equal to the length of free haul, which in this case will be taken as 800 feet, and such that its ends will be on the mass curve. The position of this line must be determined by trial. In this case, the line *a b* is at a distance above the zero line which, on the scale of 5,000 cubic yards to the inch, represents 400 cubic yards. This means that only 400 yards are involved. All the material between *a* and *b* is hauled a smaller distance than 800 feet, and therefore that material is not involved in the question of overhaul. Even the material to the left of *a* that is used to make the fill to the right of *b* is entitled to a haul of 800 feet without extra charge. Extra charge is based on the *excess* distance that these 400 cubic yards must be hauled. This excess haulage is, therefore, measured by the sum of the two triangles in the corners of the mass curve, one of them at the left of *a* and the other at the right of *b*. In this case, the allowance is evidently so small that it might be ignored, but for the sake of illustration it will be worked out. The point *a* corresponds to Sta. 125 + 60. The base of the triangle between *i a* and the zero line is, therefore, 90 feet, or .90 station, and the area is $\frac{1}{2} \times .90 \times 400 = 180$. The point *b* comes at Sta. 133 + 55, and the area of the triangle between *b t* and the zero line is, therefore, $\frac{1}{2} \times .11 \times 400 = 22$. Adding 22 to 180 we have 202. An allowance is sometimes made of 1 cent for each cubic yard hauled each 100 feet of excess distance. On this basis, the allowance in this case would be $2.02, since the sum of the two areas represents a

haulage of 202 cubic yards hauled an excess distance of one station—or, to put it more correctly, 400 yards hauled an average excess distance of .51 station or 51 feet.

COST OF EARTHWORK

54. General Considerations.—The cost of earthwork is a very variable quantity, which depends on many different items of cost. A reliable estimate of it can be made only by one that is enabled to study the local conditions and whose judgment has been trained by experience in such work. The only safe rule for one of limited experience is to classify all the items and analyze them carefully. The principal items whose cost he will ascertain as closely as possible are those given in the following article.

55. Items of Cost.—The first general item is that of **loosening** material. By hand methods, this is accomplished with picks, plows, steam shovels, or, if the material is very hard, by blasting. The steam-shovel method includes the item of loading, which is made a separate item in hand work. The blasting method is so important that it will be treated in a future article.

The item of **loading** will be a separate item when the material is loaded by shovelers, or shoveled by hand into carts or cars. When rock has been blasted out and the rock is of such character that it becomes loosened in rather large masses, it may require to be loaded with derricks. This requires a separate item of cost.

The item of **hauling** is perhaps the most variable item in the cost of earthwork. Although there are some parts of this expense that are independent of the distance, yet the cost of hauling depends very largely on the length of the haul, and the magnitude of this item justifies the elaborate calculations for haul that have been referred to in previous articles. The judgment of the engineer is called on to decide the best method of haul for given conditions. As an extreme limit of short haul may be mentioned side-hill work, where the material excavated from the up-hill side is

formed into an embankment on the down-hill side, and the labor of haulage is reduced to the throwing of the earth a distance of 6 or 8 feet. Scrapers are utilized for very short distances, and in this case the total cost of operating the scraper covers the items of loading and hauling. In very soft material, it may even include the item of loosening, although it will usually pay to have the material loosened with a plow before using the scrapers. Wheelbarrows are also employed for short distances. As the distance increases, economy requires that wheelbarrows and drag scrapers be discarded, although wheeled scrapers may be economically used for distances up to 300 or 400 feet. Carts and horses are economically used for distances up to 1,000 feet. If the distance is very much greater, and especially if the magnitude of the work is very great, it becomes economical to lay a temporary track and use cars hauled by horses or mules. If the magnitude of the work justifies a still more extensive plant, the track is made heavier, the cars have a larger capacity, and are hauled by locomotives. The magnitude of the work may increase until the track, cars, and locomotives are all standard railroad size, and the haul may be economically made for a distance of 5 or even 10 miles. Only the best judgment aided by experience will decide when it is the most economical to haul earthwork for a long distance or to borrow and waste material when the cuts and fills are not evenly balanced.

56. Some minor items that form a very small percentage of the total cost are here mentioned, chiefly to call attention to the fact that they are proper items of expense, and that the neglect to incur these expenses may result in a far greater loss than any supposed economy by avoiding them. One such item is **spreading,** which refers to the expense of keeping a few laborers employed in properly disposing and compacting the individual loads deposited by carts and cars. Another item is that of **keeping the roadways in order.** In the case of cars running on rails, this item is considerable, and is of course absolutely essential,

but a little labor in this respect, even when carts and horses or wheelbarrows are used, is true economy.

An estimate of the items of **repairs, wear, depreciation,** and **interest on cost of plant** will never be neglected by an experienced contractor, especially as these items are very large in earthwork operations. Shovels and picks wear out in a short time. Carts and cars require constant expense for repairs and maintenance, and their maximum life is but a few years at the most. The items of **superintendence** and **incidentals** should not be neglected.

BLASTING

57. Explosives.—The cost of blasting depends principally on: (1) *cost of explosives;* (2) *cost of drilling;* and (3) *cost of exploding a charge.* The various blasting compounds now used vary from ordinary blasting powder to the higher grades of explosives, of which nitroglycerine is the most common basis. Pure nitroglycerine is very seldom used, on account of the difficulty of handling it safely. The explosive compounds commonly used consist generally of a variable percentage of nitroglycerine mixed with some explosive material, which is not only of less cost but makes the compound less liable to explode prematurely. Dynamite is made by saturating inexplosive material with varying proportions of nitroglycerine. The inert matrix is capable of absorbing about 75 per cent. of nitroglycerine; in other words, 1 pound of that grade of dynamite would contain about .75 pound of nitroglycerine. This is called No. 1 dynamite. Such dynamite is about six times as powerful as the same weight of black blasting powder. The blasting powder is usually spoken of as slow burning, but its effect is greater in a soft tough rock than the nitroglycerine compounds, which are detonating, and are most effective in shattering a brittle rock. Some powders are called *slow burning* because it has been proved that the fire is communicated from grain to grain. A *detonating powder* is one that, when jarred, or detonated, undergoes a chemical change

that affects all parts simultaneously and instantly transforms the solid particles into a very hot high-pressure gas. The expansion of this gas causes the explosion.

It is often said that dynamite can be set on fire and will burn harmlessly without exploding. Since numerous explosions have occurred, even when heating dynamite to thaw it out, it is probable that a chemical change may take place in dynamite that causes it to become more explosive than when in its normally pure state. Fortunately, other explosives are now being introduced that are far less dangerous than dynamite, since it seems to be impossible to explode them except by the normal process, using a fulminating cap, as explained later.

58. Drilling.—Hand drilling may be either *churn drilling* or *hammer drilling*. In any kind of work where the drill holes may be made vertical, the churn drill is the most economical hand method. The work of operating a churn drill somewhat resembles the process of churning milk. A rod or pipe about 6 to 8 feet long is welded to a steel drill. The drill is raised by hand and allowed to fall by its own weight. As it is raised, it is slightly rotated so that the edge drops in a different direction for each fall. Where the space is confined, as in a tunnel heading, or where the nature of the rock strata requires that the drill holes shall be inclined, or perhaps horizontal, hand drilling must be done by hammer. By the light-hammer method, one man handles both the drill and the hammer. It is found that the light-hammer method is more expeditious, although perhaps not so economical as the heavy-hammer method. By the latter method, one man holds the drill and two or more men use heavy sledge hammers and strike the drill in turn, the drill being slightly rotated between each two strokes. Machine drilling is far cheaper than hand drilling, provided the magnitude of the work is sufficient to justify the installation of such a plant. The best form of drill is that which has a plain chisel edge, slightly wider than the diameter of the rod and slightly rounded along the edge.

59. Tamping is a very necessary feature of successful blasting. The tamping material is usually the earth or powdered rock that is at hand, but clay is far better and should be used if readily obtainable. The tamping should be done with a *wooden* or *copper* bar, as an *iron* bar may produce sparks, which will explode the charge.

60. Exploding.—Blasting charges are sometimes exploded by means of a fuse, which is essentially a cord of loosely woven material thoroughly saturated with powder. The fuse is usually wrapped with some protecting material, which, in the better quality of fuse, is made of rubber. Such a fuse is sufficient to explode ordinary blasting powder. Dynamite is exploded by means of the minor explosion of a small easily ignited charge. This charge may be exploded by an ordinary fuse leading into a small charge of powder. A better plan is to use a cap filled with fulminate of mercury. This is a powerful and costly explosive, but the quantity required in each cap is very small. The caps are exploded by electricity. In one form they are provided with a platinum wire, which is heated to redness by the passage of an electric current. Such work is almost invariably done by preparing a very large number of holes and wiring them to some central point from which they are all exploded, either simultaneously or in quick succession. To explode them simultaneously is simpler and takes less wiring, but there is the disadvantage that it is uncertain whether each blast has exploded.

61. Cost.—Roughly speaking, the cost of blasting varies between the extremes of 30 cents per cubic yard for brittle rock to about $1 per cubic yard for rock that is hard and tough, and in which the strata are so inconveniently placed that it is difficult so to drill the holes that the blast will have its greatest efficiency.

RAILROAD LOCATION

THEORY

1. Economic Considerations.—The economic questions that affect the projection of a railroad, while largely matters of engineering, are generally settled by the projectors of the road. It is usually understood that a proposed railroad is to be built and that the projectors have sufficient financial resources with which to build it. In projecting a given railroad, the main factors to be considered are: (1) the estimated cost of the proposed line in relation to its probable revenue; (2) the estimated cost of operation and maintenance; (3) the financial resources of the owners.

These considerations are determining factors in the construction of almost all railroads, and it is the duty of the locating engineer to harmonize them so as to obtain the best possible results for the money expended in building the road. For example, if the route of the proposed railroad traverses a region that is thinly settled and that will be dependent on the road for development, it is a wise policy to build the road as cheaply as possible, consistently with economy of operation, and to provide for future improvement in location when such improvement will be justified by increasing business. On the other hand, if the road is to be built through an old and thickly settled country where traffic will be heavy, the cost of operation and maintenance will probably be the most important consideration. In such a case, easy grades and light curves should be used as much as possible, within the limits of permissible cost for construction.

Lastly, the financial resources of the owners or projectors and the amount they are willing to spend in constructing the road will necessarily govern the engineer in projecting the location.

2. The preliminary considerations having been decided, the problems to be solved by the engineer are: (1) the selection of the general route between the two established terminal points; (2) the adaptation of the line in detail to the topographical conditions existing along the route selected.

3. Selection of Route.—The selection of the best from several possible routes is often the most difficult problem to solve; for the future of the road often depends on a wise selection of the route. The engineer should bear in mind that a railroad is a commercial enterprise, and is constructed solely for profit. In comparing the merits of alternative routes, the estimated cost of construction, operation, and maintenance must be determined before the final route of least cost and greatest value can be fixed.

4. Relative Economy.—The relative economy of different routes should be carefully considered. The cost of completion to subgrade is not always a deciding factor. The cost of the operation and maintenance of the road is frequently of more importance than the amount of yardage required to complete the grading. For example, it may be better to select one side of a valley in preference to the other, even if the work is heavier, in order to avoid snow slides (which will increase operating expenses), or because one side is more exposed to the sun than the other and is consequently more quickly freed from snow.

The engineer should be able to form an approximate idea of the comparative cost of different lines from the character of the soil, the amount of bridging, the amount of timber available for use along the line, the proximity of good building stone to the line, the probable cost of right of way, etc. These and other important points should be carefully considered for each line before a decision is made. Familiarity with the relative cost of work is only acquired by experience,

but the young engineer can obtain good results by careful study and observation.

5. Controlling Points.—The line of a proposed railroad must usually pass through or near certain fixed points, which are called **controlling points**, since their positions control the location and direction of the road. These points may be either *natural* or *artificial*.

6. Natural controlling points consist of stream crossings, summits of ridges, valleys, and other natural features of the territory through which the road must necessarily pass in order to come within the limit of permissible cost for construction. Thus, if it should be required to

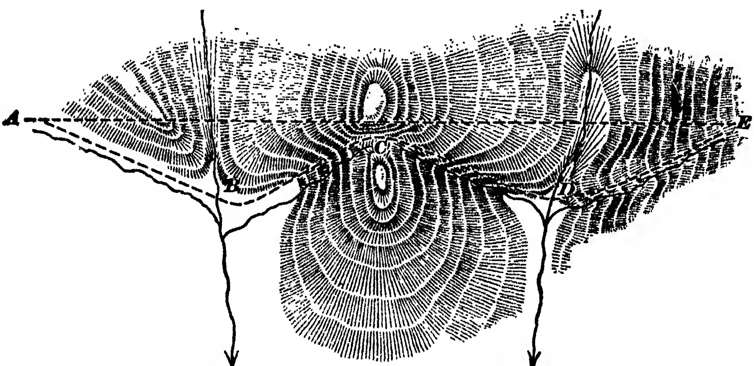


FIG. 1

construct a railroad between *A* and *E*, Fig. 1, it would be impossible to build the direct line *A E* at any reasonable cost. The natural route is that which follows the tributary stream from *A* to the main stream at *B* and then up the tributary from *B* to *C*; thence to *D* and *E*, as shown by the crooked line. The points *B* and *D* are selected with regard to their suitability for the sites of bridges across the two main streams; the lowest point *C* in the summit of the ridge is given the preference, since the cutting required at that point will be less than would be necessary to allow the line to pass through at any other place on the ridge. For similar reasons, points *A* and *E* are selected. The points *A*, *B*, *C*, *D*, and *E* are natural controlling points.

7. Artificial controlling points are those determined by the positions of towns, manufacturing sites, industrial plants, etc., through which the road must pass to secure good business, regardless of ordinary engineering considerations. For example, if a railroad has been projected to run from A to B, Fig. 2, and there are no natural difficulties in the way, the direct route along the straight line $A B$ would naturally be selected, because it is shorter and therefore cheaper to build than any other. For business reasons, however, it might be decided to take in the two important towns C and D, following the route shown by the solid line. Such a route, while longer than the direct line $A B$, will probably be much better to adopt, since the business gained by passing through C and D may more than compensate for the greater cost of construction and increased operating

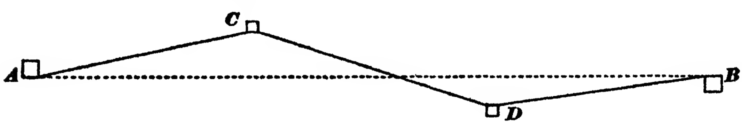


FIG. 2

expenses. In such a case, the towns C and D are artificial controlling points, and the problem for the engineer to solve is to find the best location along the route $A C D B$.

8. Engineering Conditions Affecting Location. The factors with which the engineer has to deal in order to determine the best possible route for a proposed railroad are: (1) *volume of traffic*, (2) *distance*, (3) *rise and fall*, (4) *curvature*, and (5) *maintenance of road*. These will now be considered in order.

9. Volume of Traffic.—Many items of current railroad expenses, such as interest on cost of construction, salaries of officers, and some items in the cost of maintenance are not materially affected by the volume of traffic. Thus, for a given railroad, these items will not be materially greater for a traffic of three trains per day than for a traffic of only two trains per day. The operating expenses, however, vary according to the number of trains run, and also according to

the distance run by each train, and are usually computed at so much per train per mile. The basis of comparison is therefore the **train-mile**, and the cost of any probable traffic should be estimated on the cost per train-mile.

The amount that can profitably be expended in improving the character of the location of a railroad depends on the traffic expected. If a road is projected for light traffic, it is usually best, from an economic standpoint, to use heavy grades and sharp curves in order to make the construction cost as low as possible. If, however, a heavy traffic is expected, a line involving a much greater cost for construction, but having light grades and easy curves, will usually be preferable.

10. Distance.—The effect of distance on the operating expenses of a railroad varies usually according to the number of train-miles. Differences in distance not exceeding 2 or 3 miles in a road or a division whose length is from 75 to 100 miles do not materially affect train wages or track force. Greater differences, however, affect both train wages and track force, and must be taken into consideration when comparing alternative lines.

11. Rise and Fall.—The effect on cost of operation of light gradients or small undulations in the grade line of a railroad is comparatively small. A line with light undulating gradients is generally preferable to one with long stretches of grade in one direction. When a range of mountains is to be crossed, in which there is considerable difference of elevation between the foot and the summit, it is usually advisable to select a route in which the climb is concentrated in a comparatively short stretch of heavy gradient, in preference to one where the ascent is distributed over a long distance. On the heavy gradients, pusher or assistant engines may be used to take heavy trains over the summit. In this way, by using the same motive power, except at the steepest grades, longer trains can be hauled over the whole line than could be hauled on a line with easier but longer grades. The Great Northern Railroad

crosses the Rocky Mountains with easier gradients than are used by the Canadian Pacific Railway in crossing the same ranges. The Canadian Pacific Railway, however, has a far better location for operating than has the Great Northern Railroad, since the heavy-grade sections of the latter road are distributed over a distance of 650 miles, while the heavy grades of the former road are concentrated in one division of 125 miles, where assistant engines are used.

12. Curvature.—Curvature has a considerable effect on the cost of operation, as it adds very greatly to the train resistances. The amount of curvature should be made as small and the radii of curves as large as economic and topographical conditions will permit. Usually, a certain rate of curvature is adopted as the maximum permissible, depending on the character of the country. Maximum curves, however, should be employed only where absolutely necessary.

13. Maintenance.—The expense of maintaining the track and roadway may be materially affected by local conditions along the route. A line that crosses a large number of streets or important highways, where overcrossings or undercrossings have to be constructed, or where watchmen must be stationed, will require a considerably greater expense for maintenance than a line that avoids such features. Similarly, a line built near the foot of clay bluffs or on a sliding hillside will be more expensive to maintain than one built on firm, solid material. The character and number of streams to be crossed have also a considerable effect on the cost of maintenance.

14. Towns and Terminals.—Towns, which are always the main sources of traffic, and terminals, which, besides being sources of traffic, are the main points of traffic exchange, are points of vital importance to the road. No expense within the command of the company should be spared in reaching the centers of towns and in providing the best traffic facilities. A small saving in time and a

small increase in comfort will, other things being equal, secure the traffic. Where the new line comes in competition with old and favored lines, no pains that tact or ingenuity can devise should be spared to induce favor and patronage. Ample terminal grounds should be provided at any reasonable cost, as lack of them places the road at a great disadvantage.

RECONNAISSANCE

15. Definition.—Before making a decision as to the relative merits of the possible routes, and before beginning the survey of the line, the engineer should make a careful reconnaissance of the country through which a projected railroad is to pass. A **reconnaissance** is a rapid examination of a belt or strip of country lying between the terminals of a proposed road.

16. Purposes of a Reconnaissance.—The objects of a reconnaissance may be stated to be as follows: (1) to determine the most feasible and economical line between the terminal points; (2) to locate the controlling points, both natural and artificial; (3) to determine the maximum grade and the maximum rate of curvature; (4) to ascertain the kind of material likely to be encountered in the construction of the road, and to determine the effect of the material on the cost of maintenance; (5) to note the resources of the country and its capabilities for future development, and to calculate the probable effect of the building of the road on this development; (6) to obtain a general idea of the approximate cost per mile and of the total cost of the completed road.

17. Use of Maps.—Before undertaking a reconnaissance, the engineer should procure the best available maps of the region under consideration. The United States Geological Survey has issued topographical maps of some parts of the United States. Such maps are sold at a small price by the government, and from them a great deal of valuable and reliable information relating to topographical features can be easily obtained.

18. Instruments.—In addition to suitable maps, the engineer should provide himself with an *aneroid barometer*, a *hand level*, and a *pocket compass*.

Aneroid barometers, if carefully used, are of great value in determining comparative elevations at different points along a route. It is sometimes important to know the difference in altitude between a gap or pass in a mountain range and the valley below, or between two gaps in the same range, and this can be most readily accomplished by means of the aneroid. A description of this instrument is given in *Leveling*.

A hand level is of great value for reconnaissance, and should be freely used. This instrument is useful in determining approximate differences in elevation between visible points that are not readily accessible. By its use the rate of rise or fall in the slope of a stream or of a mountain side can be rapidly determined. The hand level is fully described and the use of it illustrated in *Topographic Surveying*.

A pocket compass is necessary for determining directions, and for getting the bearings of roads, streams, and valleys along the route. It is useful for checking the courses of streams and valleys that are shown on the map, and is frequently of great value in maintaining a given course or direction through wooded country.

19. General Directions.—Having carefully studied the best available maps, and provided a suitable equipment of instruments for the reconnaissance, the engineer should take the field and make a personal examination of the region to be traversed. From a fairly good map, he can get some conception of the direction, length, and location of any streams to be crossed or followed by the line, as well as a general knowledge of the positions of mountains, valleys, or plateaus along the route. For a knowledge of local topographic conditions, however, he must rely on a personal examination, based on information obtained from local guides and by inquiry among the inhabitants. Nothing should be taken for granted, nor too much dependence placed

on local information or reports; the engineer should, as far as practicable, himself observe actual conditions. It must be borne in mind that a reconnaissance should not be confined to a narrow strip of country along a single line. An examination should be made of an area or belt of country wide enough to cover any possible choice of route. The engineer should first determine the position, character, and limiting effect of the natural or artificial controlling points along the route, and afterwards connect such points by the most suitable line.

20. Unfavorable Reports and Misleading Appearances.—The engineer should not be unduly influenced by unfavorable reports concerning the topography of a route or of a locality. It is his business to get the best line, and he should spare no pains to accomplish this end. Almost every locality contains men with decided opinions concerning the merits of one or more routes; but their judgment is very often warped by local interests. The engineer should not allow himself to be discouraged by rocky slopes, swamps, brush, and timber, which at first appear to be formidable obstacles. A rocky valley, giving the appearance of difficult and expensive construction, will often prove, on careful examination, to be the cheapest location obtainable.

21. Keeping Notes.—Comprehensive notes should be made of all topographical features along the route—such as the size and direction of streams, together with their high-water marks; the slope of important waterways that must be crossed; and any other information concerning them that can be secured. Such information as can be obtained regarding the character of the soil, the prevalence of rock, the amount of timber available for construction, the amount of rainfall, etc. should be carefully noted. In addition, the engineer should note the probable quantities of excavation, embankment, and bridging per mile; the prospective fuel supply; the possibilities for business; and all other data from which an approximate estimate of the cost of the proposed railroad can be made.

CHARACTER OF ROUTE

22. Classification.—The different kinds of country through which roads are built may be classified as follows: (1) *prairie* or *plateau;* (2) *valley;* (3) *cross-country;* (4) *mountain.* These will be discussed in the order noted.

PRAIRIE ROUTE

23. A prairie line is usually projected on the route that is most direct and contains the most uniform grade between controlling points. A rolling-prairie region is frequently deceptive in appearance, since the long undulations are often steeper than they appear. In such country, it is often difficult to decide on the best line to adopt. The engineer should not accept a line as satisfactory because the gradients and curvature are within the maximum limits, but should satisfy himself that the line cannot be improved. Many bad mistakes in location have been made in prairie country, in which lines were accepted as being good enough without an attempt being made to improve the location.

24. Deceptive Appearances.—In a rolling or a hilly country, the eyesight is easily deceived and seldom gives to

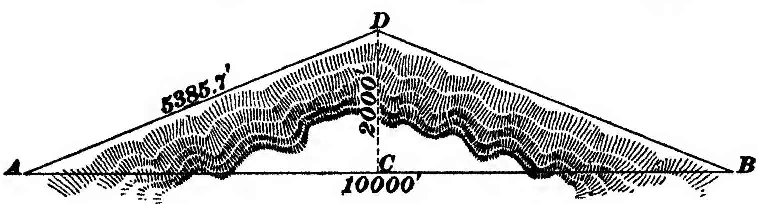


FIG. 3

objects their true relative proportions. Such deception can be attributed to two causes; namely:

1. *The eye foreshortens the distance in an air line and exaggerates a lateral offset.*

This fact is illustrated by Fig. 3, in which the points *A* and *B*, 10,000 feet apart, are in an air line between two towns, and the road must cross a ridge, the highest point of which is at *C*; the ridge flattens out at *D*, 2,000 feet from *C*, the

middle point of AB. To the inexperienced, the offset CD, as seen on the ground, will be greatly exaggerated, appearing to be fully one-half the straight line AB, and the conviction will follow that, in passing from A to B by way of D, not only will a great deal of curvature be introduced, but the length of the line will be so greatly increased over that of ACB as to make a careful consideration of the route ADB out of the question, even though the line AB should require steep grades and a heavy cut at C. This exaggeration is apparent when it is found, by calculation, that the distance from A to B by way of D is only 770.33 feet greater than the direct line between A and B. This illusion of the eye explains the aversion to swinging the line, too common among engineers, and the undue importance attached to good alinement. The

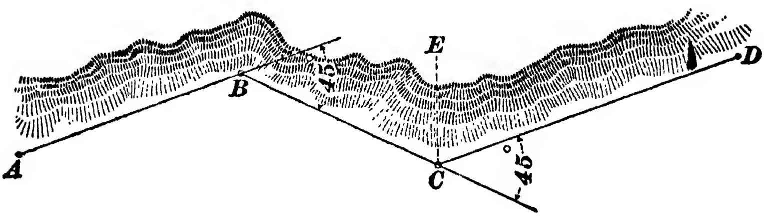


FIG. 4

chances are that the line ADB is far superior to the line ACB, both in cost and grades, while the increase in distance of the line ADB over the line ACB is less than 8 per cent.

Frequently, a deflection that will not, in reality, add more than 15 per cent. to the length of a line, will appear to double it; and the deplorable mistake is often made of adopting the air line, even though it costs much more than the deflected line would cost.

2. *The eye exaggerates the sharpness of projecting points and spurs and the degree of curvature necessary to pass around them.*

All slopes, when looked at from in front, are exaggerated by the eye. Few mountains have slopes exceeding $1\frac{1}{2}$ to 1, or $33\frac{1}{3}°$; yet the eye will estimate such slopes at from 45° to 50°.

In running the line $ABCD$, Fig. 4, the engineer, if he were to accept his natural estimate of the angles at B and C,

would make the angle at C about twice as large as the angle at B, even though he had walked over the line. The reason for this is that, while standing at any point on the line BC, his view of the line CD is cut off by the profile EC of the hill in front, and, in spite of himself, the unseen will be distorted and invariably magnified.

Nowhere is the proverb, "Appearances are deceiving," so true as in an apparently smooth or gently rolling country. The undulations are so gradual that their aggregate is rarely suspected. Abundant experience goes to prove that an air line in such a country is only possible at the cost of heavy grades and long and heavy cuts and fills. To avoid them, frequent deflections must be made, introducing curvature in proportion, though the increase in length of line is in no degree proportional to the saving in cost of construction and operation.

VALLEY ROUTE

25. When the route of the proposed railroad is along the valley of a stream, the reconnaissance problem is presented in its simplest form. If the stream is of considerable size, the object of the reconnaissance may be to decide on which side of the stream to run the line. In such a case, both sides of the valley should be carefully examined, and the leading topographic features noted. Unless one side is decidedly better than the other, the determining points affecting the construction and operation of the road should be carefully noted for both sides. Such points are: (1) the relative value of property on the two sides; (2) the number and size of tributary streams, and the probable cost of bridging them; (3) the relative volume of material to be removed; also, the character and cost of handling, and the liability to landslips; (4) the total estimated amount of curvature and the maximum degree of curvature required on either side; (5) the probable business that would be obtained on either side. If these points are carefully considered and the results compared for both banks of the stream, the bank showing the more favorable result is obviously the better route.

If the waterway in question is a small stream, the best line will probably cross it at intervals, in order to reduce the amount of work to a minimum. Where bridging is necessary, the banks of the stream should be examined for suitable locations for abutments and piers.

CROSS-COUNTRY ROUTE

26. Cross-country lines are more frequently used than any other, since most railroads are built across the country to connect terminal points. In a line running across the country, several summits have usually to be surmounted. Here the chief object of the reconnaissance is to determine the gaps or lowest points in the ridges, and the highest banks at stream crossings, in order to reduce to a minimum the total rise and fall, as well as the amount of work required in construction. Most railroad lines of any length combine the characteristics of both valley and cross-country routes. In such a case, the selection of the best line will not only call for judgment and skill, but also entail a considerable amount of hard work.

27. The engineer should bear in mind that, while there is only one best line on any given route, there are always two or more lines from which to make a choice, the problem being to determine which of them is the best. In Fig. 5 is illustrated a case from actual practice bearing on this point. The line had followed the river *AB* for several miles, keeping a uniform grade of about 30 feet per mile. It became necessary to leave the river valley and climb a ridge in order to reach a town lying in another valley. The entire country was thickly covered with timber and undergrowth, and consisted of abrupt, irregular hills (called **hog-backs**). The brook *C* was known to the engineer, who endeavored to trace it to its junction with the river, but the brook lost itself in a cedar swamp at *D*, and it was impossible to find the outlet. After repeated attempts to find the outlet, only to encounter each time the ridge *E* that lay between the river and the valley *D C*, he continued the line up the

river, and crossed the latter at B, where a precipitous ledge prevented any further progress along the river. He therefore crossed the neck of land F, and the river at G, and climbed the ridge, doubling about the sharp headland at H; then, swinging backwards, with a heavy fill at M he proceeded with the line KL. Although this seemed to be the only

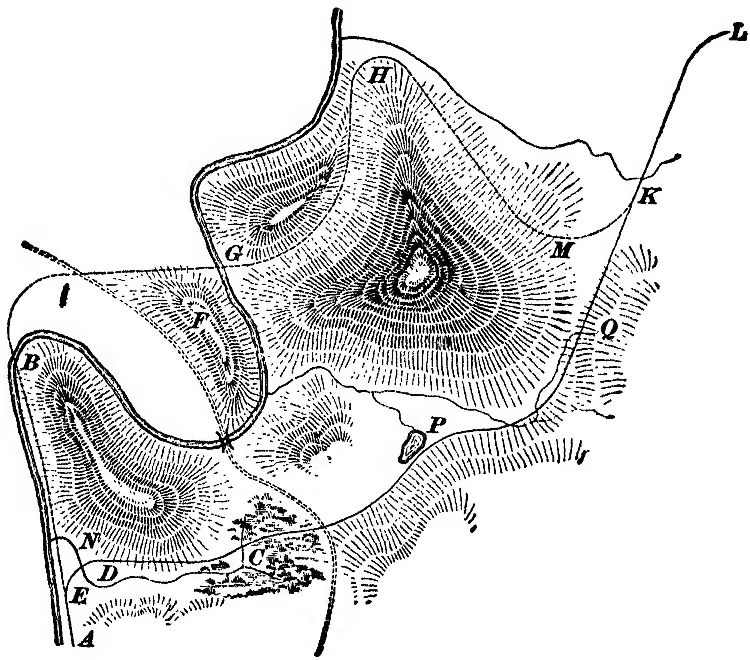


FIG. 5

possible route, it was so rough and crooked that the engineer determined to make another trial. After tramping around for 2 days in a heavy rain storm, he discovered the narrow opening at N through which the brook found its way. He also found the brooks P and Q, and ran a satisfactory line from E to K, with the result that two river bridges and 3 miles in distance were saved, although to get through the ridge at E required a heavy cut

MOUNTAIN ROUTE

28. In a mountainous region, the chief matters to be taken into consideration are usually the lowest crossing points—or **passes**, as they are commonly called—through which to run the line with a minimum cut and grade. Very often, it is impossible to find a direct route through a pass, with gradients that are within permissible limits. Sometimes, the slope of the surface is greater than the adopted maximum grade, and, in order to pass from one side of a divide to the other, it is necessary either to construct a long tunnel or to increase the length of the line to such an extent that the ascent or descent can be made on the required gradient.

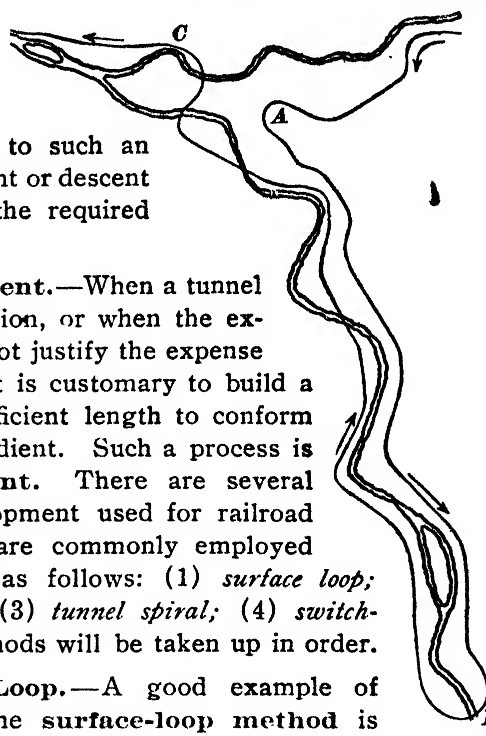


FIG. 6

29. Development.—When a tunnel is out of the question, or when the expected traffic will not justify the expense of a long tunnel, it is customary to build a surface line of sufficient length to conform to the adopted gradient. Such a process is called **development**. There are several methods of development used for railroad lines; those that are commonly employed may be classified as follows: (1) *surface loop;* (2) *bridge spiral;* (3) *tunnel spiral;* (4) *switchbacks*. These methods will be taken up in order.

30. Surface Loop.—A good example of development by the **surface-loop method** is illustrated in Fig. 6, in which is shown a plat of the Michael Creek loop on a branch of the Canadian Pacific Railway. From *A* to *C*, the distance in an air line is less than 2,000 feet, while the difference in elevation is 200 feet. The adopted maximum gradient was 1 foot per hundred;

hence, a direct line from A to C was out of the question, since it would require a gradient of 10 feet per hundred. It was necessary, therefore, to develop the line between A and C in such a manner as to obtain the necessary distance to conform to the maximum gradient. This was accomplished by following the valley of the tributary stream as far as B, where a loop was made, and then returning down stream to the desired point, the entire distance being on the maximum gradient.

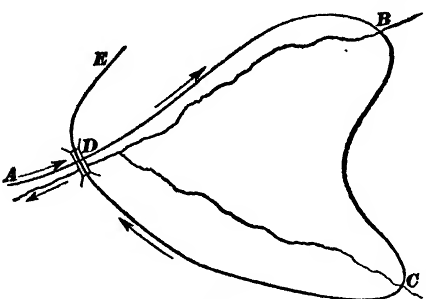


FIG. 7

31. Bridge Spiral. Where the topography will permit, the development of a line is sometimes made by means of a **bridge spiral.** In such a case, the line is made to cross itself by means of a bridge or a tunnel, the parts of the line that cross each other being

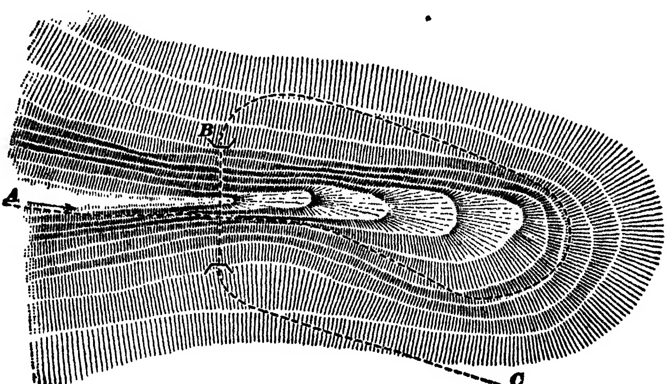


FIG. 8

at different elevations. In Fig. 7 is shown a bridge spiral, in which the upper end of the spiral is carried over the lower end on a bridge or viaduct. In ascending from A to E, the line follows the stream to B, where it crosses and continues to C, thence over the tributary stream still ascending, the

line crosses itself on the bridge at *D*, and, on reaching *E*, gains the elevation desired.

32. Tunnel Spiral.—In Fig. 8 is shown a **tunnel spiral,** where the line, descending from *A*, forms a spiral whose lower end passes under its upper end through a tunnel at *B*.

33. Switchbacks.—Where precipitous slopes are encountered that will not allow of any other treatment, the required development may be made by the use of **switchbacks.** In this method, the train is switched to a spur track, the switch thrown for another track at a higher elevation, and the train backed over on to this track, the operation being repeated as many times as necessary to reach the desired level. When switchbacks are used, they should be laid out in pairs, somewhat as shown in Fig. 9, in which the train, in ascending from *A* to *D*, passes over the switch *B* to the spur, runs backwards to the switch at *C*, and then goes forwards to *D*.

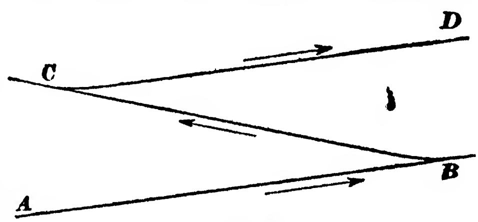


FIG. 9

As already stated, switchbacks are useful for overcoming differences in elevation in a limited space, where other forms of development are impracticable; but they are slow in operation, since two complete stoppages are necessary for passing and repassing switches, and part of the distance between the terminal switches must be run backwards. Switchbacks are seldom used on important railroad lines except as a temporary expedient in cases where it is expected to replace them with a tunnel at some future time.

PRELIMINARY SURVEY

34. Character of the Survey.—The reconnaissance having been completed and a route selected, the next thing is to make a **preliminary survey.** This consists of an instrumental examination of the route for the following purposes: (1) to obtain the necessary information for making a map and a profile of the route; (2) to furnish data from which to project the location; (3) to determine, approximately, the amount of work to be done in the matter of clearing, grading, and bridging, and to furnish data for an approximate estimate of cost of the proposed road; (4) to determine the relative merits of alternative routes that have been examined on the reconnaissance.

The preliminary survey may be more or less elaborate, according to local conditions, the degree of accuracy necessary, and the amount of information required. The work should be done as expeditiously as possible, consistently with general accuracy, and should not be delayed for the sake of precision in minor details.

35. Organization of Party.—A complete party for making a preliminary survey through a thinly settled region is usually made up as follows: (1) the *locating engineer*, or *chief of party;* (2) the *transit party*, consisting of a *transitman*, a *head chainman*, a *rear chainman*, a *stakeman*, and one or more *axmen;* (3) the *level party*, consisting of a *leveler*, a *rodman*, and, in wooded country, an *axman;* (4) the *topography party*, consisting of the *topographer* and one or two assistants; (5) the *commissary* and *camp outfit*, which, in a thickly settled region, is seldom required, the party usually boarding at convenient farmhouses along the route.

EQUIPMENT

36. Surveying Instruments and Accessories.—The surveying party should be provided with one engineer's transit; one wye level; two 100-foot tapes of medium steel; two transit poles; one Philadelphia level rod; one hand level; one aneroid barometer; one pocket compass; one hand ax, with extra handles; from two to six axes, with extra handles; two 50-foot metallic tapes; and several pounds of red marking chalk. In a prairie or open country, a supply of stakes should be kept constantly on hand. In a wooded country, stakes are preferably cut along the route as the survey progresses.

The steel tape has now almost entirely replaced the old-fashioned heavy link chain. It is well to be provided with an extra tape, and with some one of the numerous appliances for mending tapes. A convenient way of mending a broken tape is to first straighten the ends, if necessary, of the two pieces of the tape; then insert the broken ends until they meet at the middle of a "sleeve" about 2 inches long and of the proper cross-section, lined on the inner side with solder. By pressing a heated iron on the sleeve, the solder fastens the sleeve to the tape.

37. Office Equipment.—A large drawing board, one straightedge, two rubber or celluloid triangles, one horn protractor, one large paper protractor, a pocket case of drawing instruments, a supply of drawing paper, profile paper, pens, ink, erasers, and pencils will constitute a fair office equipment for platting the field work. In addition to these articles, a supply of note books, comprising transit books and level books, should be provided. The stationery supplies should be carried in a camp chest or stationery chest made for the purpose.

38. Camp Equipment.—When a camp outfit is necessary, the following equipment can be used: three heavy duck or canvas tents, equipped with flies or covers; one wagon and team; one cook stove, with cooking utensils; and a supply of provisions.

The tents should be of good size—preferably 12 ft. × 12 ft., or 12 ft. × 14 ft. in dimensions—and provided with the necessary guy ropes, tent pins, etc. One tent, which is used as an office, contains the stationery chest and drawing board, and is occupied by the chief of party, the transitman, the leveler, and the topographer. Another tent is occupied by the rodman, the chainmen, and the axmen. The third tent is used as a kitchen, and is occupied by the commissary and the cook. In the winter season, a fourth tent should be provided to shelter the team.

39. Medicine Kit.—When a survey is made through a thinly settled country, the camp outfit should include a small box or chest containing a few simple standard medicines. Such a box, which is called a **medicine kit**, should be proportioned to the size of the party, the climate, and the distance from skilled medical attendance. For surveys of considerable length through a sparsely settled country, a complete assortment of suitable medicines should be provided; but for ordinary railroad surveying, the following medicine kit will be found sufficient for most purposes: one 4-ounce bottle castor oil; one 4-ounce bottle brown mixture, for coughs; one 4-ounce bottle extract Jamaica ginger; one 2-ounce bottle Worburg's tincture, for fevers; one 2-ounce bottle Sun cholera mixture; one 4-ounce bottle Pond's extract; one roll of court plaster; one box cathartic pills; one hundred 2-grain quinine pills; one package soda-mint tablets; one package Dover's powders; one pint bottle of whiskey or brandy. A box or case about 7 inches long, 6 inches wide, and 4 inches deep will be large enough to carry all ordinary medical supplies.

FIELD WORK

40. Use of Transit or Compass.—In running the line for a preliminary survey, either the engineer's transit or the surveyor's compass may be used. The engineer's transit is the instrument most commonly employed, although some engineers prefer the surveyor's compass.

A compass is light, easily and quickly set up, and more convenient to carry than a transit; on this account it is preferred for long journeys over rough ground. When the compass is used, the directions of the courses are fixed by their magnetic bearings.

On preliminary survey work, however, the transit is generally given the preference, because it is more accurate and its range of sight is greater than that of the compass. Besides, the transitman can tell at once whether the ground in front is rising or falling, by setting the telescope level and noting where the horizontal hair cuts the rod in the hands of the front chainman. The inclination of a slope can be quickly determined by sighting through the telescope of the transit to a point on the front chainman's rod that is of equal height with the instrument. This operation is often necessary, especially in making a survey to conform to a fixed gradient on a mountain slope or on the slope of a stream.

41. Alinement.—A preliminary survey usually consists of a series of straight lines or tangents connected by angles at the points where changes in direction occur. When a thorough reconnaissance has been made, the preliminary survey should follow more or less closely the line that will be adopted for the final location. In this case, the line should conform as nearly as possible with a surface line that coincides with the adopted gradient; such a line is called a **grade contour.**

In turning angles, they should be taken to the nearest degree, half degree, or quarter degree, to facilitate platting. Abrupt changes in direction, or very sharp angles, which cannot be covered by the maximum curvature, should be avoided, since the preliminary profile in such cases will not be a true guide for the location profile, and is likely to create a false impression of the situation.

42. Chief of Party.—The locating engineer is usually the **chief of party**, and, as such, has general supervision over the party in the field. He selects the route of the

survey, makes arrangements for camp sites or stopping places, and looks after the general progress of the survey. He should take notes of the available quantity and the quality of construction material along the route, select suitable stream crossings, and estimate approximately the sizes of culverts and openings required. He should also keep in close touch with the survey, especially in difficult country and in localities where it is necessary to follow closely a grade contour. In such cases, he keeps just ahead of the party, using a hand level or clinometer when necessary, and selects suitable ground for the line. He fixes the points where angles are to be turned, and from them signals to the transitman. Where the chief of party cannot be seen from the transit on account of the underbrush, he usually signals by shouting, the transitman pointing the instrument in the direction indicated by the sound. This preliminary sighting is checked as soon as the survey has progressed far enough or a sufficient clearing has been made to enable the transitman to see the forward signal. Where the line is not on suitable ground, the chief of party either makes an offset to the required place and continues the survey, or orders the party to go back to a suitable point and start a new line.

The chief of party should keep on friendly terms with landowners and residents along the route, and endeavor to obtain their good will for the proposed road. He should see that property is not injured unnecessarily by the members of the party, and should settle damages caused by the survey passing through cultivated fields.

43. Transitman.—Next in authority to the locating engineer is the **transitman,** who takes charge of the party in the absence of the chief. The transitman runs the transit and directs the operations of the transit party. He gives line to the front chainman at each setting of the transit rod, either for a station stake or for a guide to the axmen when there is clearing to be done. He measures and records the angle at each change of direction, and reads and records the bearing of each course. He should keep his instrument

in adjustment, and, on survey, make full and complete notes of the work done by the transit party.

The transit notes should be kept in a regular transit book, and should be plain, distinct, and easily understood. On the left-hand page are entered, in successive columns, the number of the station, the deflection angle, the magnetic course, the calculated course, and the distance between angle points, respectively. The right-hand page is ruled into small squares, for convenience in sketching topography; while in the middle of the page is a vertical red line representing the line of the survey. Station numbers are recorded from the bottom upwards on alternate horizontal lines, the stations themselves

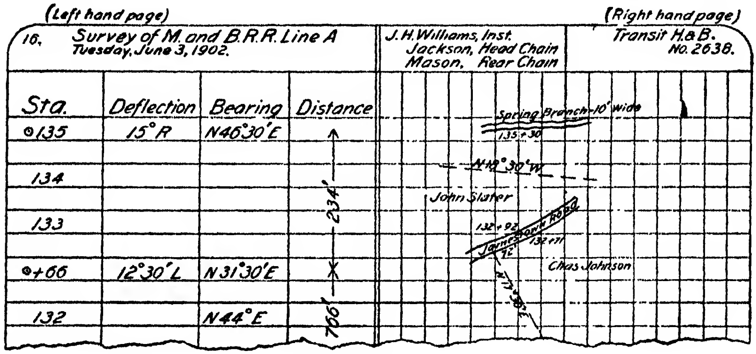


Fig. 10

being designated, at corresponding intervals, by dots on the red line on the right-hand page.

The notes should show the bearings and the names of the highways and streams intersected, their widths, and the distances from their intersections with the line to the nearest station of the survey. Property and land lines should also be shown, as well as the names of property owners when obtainable. Bearings should be taken with the transit, and distances to important land corners should be measured along land lines and recorded. The first and the last station in each day's run, together with the date and the name of the transitman and the names of the members of the transit party, should be noted.

In Fig. 10 is shown a good form of transit notes of a preliminary survey. The topography is drawn approximately to scale on the right-hand page of the notebook. The pluses—or the distances from the next preceding station to the intersection of the survey with land lines and with both sides of streams and highways—are written in figures expressing feet, as shown.

44. Head Chainman.—In running the line, the **head,** or **front, chainman** carries in one hand a transit rod, and holds in the other hand the front end of the tape or chain. When the tape is out and the front chainman is ready to set a stake, he faces the transit, holding the rod in a vertical position and the chain horizontal, with the end of the handle against the side of the transit rod, and midway between the front and back faces of the rod. He sets the rod in line, moving it to the right or the left according to signals from the transitman or the rear chainman, until it is in the required position. In measuring down a slope, he should "break chain," as explained in *Chain Surveying*. At each short measurement with the broken chain, the head chainman keeps the chain horizontal with one hand, while with the other he holds the rod at the proper place between the thumb and forefinger, in such a manner that the rod will swing freely with its foot just clear of the ground. The rod is then allowed to drop vertically to the ground, and the front chainman makes a mark on the ground where the foot of the rod strikes the surface; this serves as a point for the rear chainman to hold the chain for measuring the next section. This process is repeated until the full measurement is made. Another method of plumbing down the end of the chain is for each chainman to carry a plumb-bob, with about 8 feet of line attached to it. A light iron plumb-bob may be bought for about 5 cents, and several of them should be in the surveying outfit.

A stake is usually driven at the end of each tape length to designate the station, and as soon as each station point is determined the front chainman directs the stakeman where to drive the stake, and also calls out the number to the rear

chainman, who has previously called out the number of the station at his end of the chain.

In wooded or brushy country, where clearing is necessary, the front chainman, after advancing to the limit of the clearing and getting the line from the transitman, presses the point of his rod into the ground, causing the rod to stand in a vertical position on line. He then either goes ahead to where the axmen are clearing, and directs their work, or keeps the rod well up with the clearing, getting line from the transitman from time to time.

After locating the position of a stake, the head chainman advances to the next station. This process is repeated until he reaches the point designated by the chief of party for a change of direction. If this point is on rocky or sloping ground, or is near an obstruction, the head chainman selects the best place to set up the instrument, taking the plus at a whole foot on the tape for convenience, being careful in selecting the point to provide for an unobstructed view ahead. As soon as the point is located, he signals to the transitman, who takes up his instrument and walks over to the point. While the transitman is coming up, the head chainman ranges out the line in the new direction and starts the axmen to clearing. If there is no clearing to be done, he measures the distance from the transit point to the next station and sets the rod approximately in line before the transitman comes up. The head chainman is next in importance on the transit party to the transitman, and much of the progress of the party depends on his work.

45. Rear Chainman.—The **rear chainman** attends to the rear end of the chain, holding the end of the chain at the last stake set for a full chain measurement, and cutting off the plus to each intermediate measurement. As the front chainman advances, the rear chainman calls out "chain" in time for the front chainman to stop as the rear end of the chain reaches the stake. The rear chainman, after noting that the chain is straight and free from kinks, holds the end of it against the station stake, which he must be careful not

to disturb. As each new station is set, he calls out the number of the station at his end of the chain.

The rear chainman notes the plus to each road, fence, stream, or land line, and records this information in a notebook carried for this purpose. He is responsible for the correctness of fractional measurements, and should be careful not to mistake the 40-foot tag for the 60-foot tag, or make similar errors in reading the tape. In measuring up a slope, he should assist the front chainman to break the tape by holding his end of the length or section of tape high enough above the point to make the tape horizontal. In making such measurements, the rear chainman stands to one side of the line, and holds the required place in the tape directly over the point, using a plumb-bob, as previously described.

In all measurements along the line, the rear chainman should keep to one side of the line so as to avoid obstructing the line of sight between the transit and the front chainman. The rear chainman should accustom himself to pacing the distance between successive stations, so as to be able to determine approximately the position of each new stake, and thus save time looking for it, especially if it is hidden in high grass, weeds, etc.

46. Stakeman.—The **stakeman** prepares and marks the stakes and drives them at points indicated by the head chainman. He should keep on hand a supply of stakes, marked and ready to drive. If stakes are not provided, he makes them from suitable material along the line. The stakeman may carry his supply of stakes loose, or in a bag or basket of convenient size, or else tied in a bundle with a suitable strap. When the head chainman gets line for a station and marks it, the stakeman should drive the proper stake immediately, and proceed to the next station so as to be ready to drive the next stake as soon as the head chainman gets line with his rod. When there is much heavy clearing to be done, the stakeman should leave his stakes at the last station set and go ahead with the axmen to assist in clearing.

47. Axmen.—The number of **axmen** will vary according to the amount of clearing required. Their duties consist in clearing away the saplings, underbrush, and overhanging branches that would interfere with the sight of the transitman or the leveler. They should not waste time by making a clearing unnecessarily wide; on a preliminary survey, no trees over 3½ or 4 inches in diameter should be cut. If the line passes through a tree of larger size than this, the tree is blazed front and rear, and the line is carried around it in one of the ways explained in *Transit Surveying*, Part 2.

48. Signals.—In making a railroad survey, it is customary for the transitman and the head chainman to communicate with each other by means of signals. The signals should be plainly given, and each signal should have a meaning that will be unmistakable.

The following are the usual signals made by the transitman to the front chainman: Moving the hand horizontally to one side means that the rod is to be moved in a corresponding direction. Moving the hand vertically up or down means that the rod is to be raised or lowered correspondingly. Holding the arm straight up and inclining the extended hand to one side or the other signifies that the rod is to be plumbed by moving its top in the direction indicated. Moving both hands up and down at the same time, or whirling a handkerchief around above the head, signifies "all right." At long distances, the signals can be made plainer by holding a handkerchief in the hand when making them. If the ground is covered with snow, a colored handkerchief should be used for signaling.

When the head chainman signals to the transitman, he usually makes the signals as follows: When line is wanted, the rod is held in a vertical position and moved slowly from side to side. When line is wanted for a turning point or hub, the rod is held in a horizontal position by the front chainman, who moves it up and down once or twice. In signaling for the transitman to move up, the head chainman makes the "all-right" signal described for the transitman.

49. Stakes.—The stakes used for designating the stations should be of uniform size, suitably marked, and firmly driven. They should be made preferably of some light smooth-grained wood that can be easily marked. In a prairie country, where timber is scarce, sawed stakes are commonly employed; they are usually made $1\frac{1}{2}$ inches thick, 2 inches wide, and 24 inches long. In a wooded region, station stakes are usually made from saplings or branches of suitable size—preferably from $1\frac{1}{2}$ to 2 inches in diameter, and from 20 to 24 inches in length and are called **round stakes.** A good form for a round stake is illustrated in Fig. 11, which also shows the manner of blazing for marking and of pointing for driving. The numbers on the stakes should be marked with crayon, with the number reading

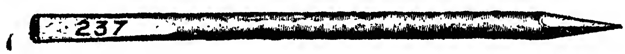


FIG. 11

from the top downwards, as shown in the figure. Each stake should be driven vertical, with the numbered side facing the transit.

50. The Leveler.—The level party follows the transit party as closely as possible. The levels of the proposed line and the line with which it is to connect should be referred to the same datum plane, so as to secure a continuous profile, especially if the levels of the established line are referred to the sea level. If such a base is not practicable, an elevation for the starting point must be assumed of such a height as will bring all elevations of the proposed line above the assumed datum plane.

In case the country is wooded, with the added hindrance of thick underbrush, the transit party will of necessity move slowly, and the level party will consequently have much spare time. The members should provide themselves with profile paper and keep the profile platted as the work progresses.

In running a grade line, it is often necessary to have the level up with or even ahead of the transit, in order to

determine whether the ground is above or below grade, and, if so, how far to shift the line to reach the desired elevation.

The leveler is responsible for the correct elevation of the ground at all stations and at abrupt changes of elevation in the surface between stations. He should determine the elevation of the water surface and bottom of channel in all streams crossed by the line, and, when possible, should get the elevation of high water on all important streams.

51. The level rod commonly used on a railroad survey is the Philadelphia rod, which is used as a self-reading rod where elevations are taken to the nearest tenth of a foot; at turning points and bench marks, the target is used, and readings are taken to the nearest hundredth of a foot. In some cases, the Philadelphia rod is used without a target, the leveler estimating the nearest hundredth by the eye when taking a reading on a turning point or bench mark. On a preliminary survey, bench marks are usually placed at intervals of from 1,500 to 2,000 feet, and are located at convenient places near the line, where they can be readily seen by the leveler without much clearing.

52. In a rough broken country, the leveler should carry a hand level for use in determining the depths of ravines or gullies crossed by the line. He first takes a reading at the top of the nearer bank, and then sends the rodman across the ravine to establish a bench mark or a turning point on the farther bank. This being done, the leveler, by using his hand level, rapidly levels down to the bottom of the ravine and up to the peg on the farther side. Sometimes, it is only necessary to determine the elevation of the bottom, in which case the levels are not carried up on the farther side.

53. The leveler on a railroad survey should be quick and accurate. He should keep his notes worked up in the field so as to be able to tell, without delay, the elevation of any given station when called on by the chief of party. In running levels on a preliminary survey, time should not be wasted on small details, but care must be taken to insure the general accuracy of the work. For example, a difference of

a few tenths of a foot in the surface elevation is not important, while an error in reading the rod on a turning point or a bench mark might cause serious results. The progress of the entire survey party is largely dependent on the speed of the leveler.

54. Rodman.—The **rodman** holds the level rod at each station and at intermediate points whose elevations are required. He should call out the number of each station as he reaches it, and should be on the lookout for mistakes in numbering the station stakes. Should a mistake in the station numbering be discovered, the leveler notes it in his level book and carries the correct numbering forwards until the transit party is notified and the mistake corrected. The rodman should note all important changes in the ground, and, where necessary, give a rod reading to the leveler, pacing the distance from the station stake to the place where the rod is held, and calling out the plus in each instance. At streams, he gives one reading at the top of the bank, one at the water's edge on each side, and one at the bottom of the channel. Where the stream is too deep for the leveler to read the rod when held on the bottom, the rodman ascertains the depth with his rod and calls out his measurement to the leveler. This depth, when added to the rod reading for the water surface, will give the rod reading for the bottom. The rodman should be on the lookout for high-water marks at all stream crossings, and should give rod readings at all such marks when they are found. He should carry a notebook in which should be kept a record of the rod readings at turning points and bench marks. In each case, he should compute the elevation and height of instrument as a check on the calculations of the leveler. The rodman should hold the rod vertical for each reading, and at bench marks and turning points he should wave the rod gently to and from the instrument to enable the leveler to determine the exact point of verticality in reading the rod by noting when the center of the target is at the highest point.

55. The rodman should be quick and active. He should exercise good judgment in selecting places for turning points and bench marks, so as to afford an unobstructed view for the foresight and backsight. He should accustom himself to pacing the distance between successive station stakes in order to quickly determine the plus to an intermediate point where a rod reading is to be given, and also to facilitate the finding of station stakes in tall grass or weeds.

56. For a turning point, some firm object, such as a projection or point of a rock, or the root of a tree, or a stump, may be used on which to hold the rod. A peg is commonly employed for a turning point, the top of it being cut square and smooth, and allowed to project a little above the surface of the ground; the rod is placed on top of the peg, which should be driven until it is firm and solid, and the top marked with red chalk in order to render it conspicuous in case it becomes necessary to return to it.

The rodman should carry a hand ax or hatchet for use in making bench marks, for making and driving turning pegs, and for light clearing. In rough or thickly wooded country, an axman should accompany the level party. His duties consist in clearing away brush and other obstructions to the view of the leveler, cutting bench marks, and assisting the rodman in his work.

57. The Topography Party.—The composition of the **topography party** on a preliminary survey is variable, depending on the nature of the country and the degree of accuracy required in the survey. In some cases, there is no regular topography party, the necessary topography notes being taken by the chief of party and the transitman. When a regular topography party is attached to a railroad survey party, the work of taking the topography is usually done in the manner described in *Topographic Surveying*. The topography party follows after the level party and secures the necessary data for making a contour map of the ground on each side of the line to such a distance as may be required. For ordinary work of this kind, the topography party consists of

a topographer and two assistants. The topographer uses a hand level to determine the side elevations, and keeps his notes in a regular transit book. The topography notes should be drawn to a scale of two lines per station, except in special cases, where much detail is to be shown, when a scale of four lines per station may be used.

The topographer should make full notes concerning the location of roads, property boundaries, fences, swamps, fields, forests, and streams crossed by or adjacent to the line. The character of the material along the line should be carefully noted, as well as the proximity and extent of adjacent rock outcrops. It should be borne in mind that the projection of a railroad line in hilly country is often materially affected by the character of material liable to be encountered

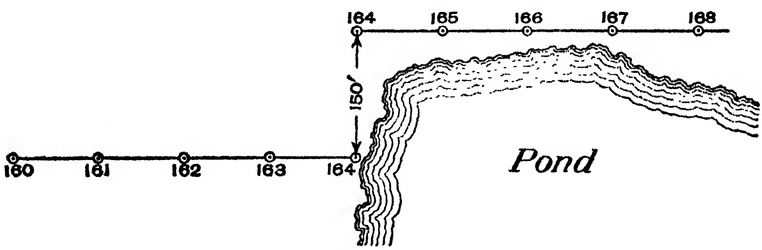


FIG. 12

in cuts or that may be available for fills. The topographer's assistants should be active and quick, and capable of handling the tape or rod as may be required.

58. Offsets.—In running a preliminary survey, it is sometimes found that the line is not on the best ground that can be obtained, or that there is some obstacle ahead that must be avoided. Under such conditions, an offset to the right or left is usually made long enough to throw the line on suitable ground or to pass the obstacle. Offsets are generally made at right angles to the direction of the line, and preferably at a full station or at some division of a station that is a multiple of ten, in order to facilitate platting. The length of the offset should be carefully measured, but should not be counted in the station numbering; that is,

the station at the beginning and that at the end of the offset should be given the same number. In Fig. 12 is shown a pond into which the line would run if produced beyond Sta. 164. At this station, an offset is made of sufficient length to clear the edge of the pond, and the line is continued from the end of the offset.

59. Backing Up.—Sometimes, after a survey has progressed a considerable distance, it is found that the line is on the wrong side of a valley or stream, or that a better line can be obtained by beginning at a point already passed.. It is then necessary to abandon that part of the line which is in the wrong place and begin a new survey at the desired point. Such a process is called **backing up**, and is frequently necessary in difficult country. All notes of the abandoned portion of the line should be crossed out by pencil lines diagonally across the page, and the word "Abandoned" written across the face of the notes.

Notes of a survey should never be erased or destroyed, even if the survey is abandoned. When such notes are crossed out, the new notes should begin at the place immediately following in the notebook, reference being made to the new page and place at the point where the old notes are allowed to stand.

60. Office Work.—At the conclusion of each day's work, the field notes, both transit and level, are carefully checked, and a plat of the line is made, either by bearings with a large paper protractor, using a parallel ruler or two triangles, or by latitudes and longitudes, carefully marking the crossings of streams and highways, and noting any important point that may enable the chief engineer to readily locate any particular section of the line. Where the country is smooth, the line may be platted to a scale of 400 feet to the inch. Rough parts of the line may require a scale of 200 feet to the inch; and where difficult country is encountered, involving detailed topographical maps, a scale of 100 feet to the inch is advisable. The line may be conveniently platted on sheets 24 in. × 30 in. in size, numbered

in regular order, each sheet containing a part of the line on the immediately preceding sheet, so that, by matching and pinning them together, a continuous map of the line may be obtained.

The topographer will bear his proportional share of the work, consisting mainly in a detailed explanation of the notes of the day's work to the draftsman, whose principal duty is to make the contour maps. In some cases, the topographer acts as draftsman; usually, however, the transitman plats the line and the topographer assists in platting the contours. The leveler will plat the day's levels on the continuous profile kept in the office, the rodman reading the notes. This profile should contain as full information as possible, especially when relating to highways and watercourses.

Some engineers prefer to wait for a rainy day in which to do the office work, but more make it an invariable rule to plat each night the work of the day. This practice enables the chief of party to have a complete record of his work always ready for the inspection of the chief engineer, who is likely to appear at any time. If he is his own chief, personal interest in the work would warrant him in making such a rule. Notes that are platted when fresh are always of more value than when stale. If the contour maps are to keep pace with the survey, the draftsman must be an expert. Each day he plats the work of the preceding day, so that, under the direction of the topographer, every point is covered.

61. Spur Lines.—In making a preliminary survey, it is often found that two points on the line may be connected by two or more routes; it is then necessary to run separate lines between such points in order to determine the best route. Such lines are called **branch lines**, or, more commonly, **spur lines**. The original survey line is called the **main line**; the spur lines are joined or tied to it at the required points.

Each spur line is usually designated by some letter, as line *A*, line *B*, etc. In comparing the relative merits of the different spur lines, the lines are platted together in order to compare the alinement. The different profiles may be compared either by platting them together on one

sheet of profile paper, using different-colored inks for the different lines, or by platting the profile of each line separately, using the same scale for all. In this way, the engineer, knowing the topographical features and the character of the material on the different lines, will be able to study the characteristics of each line in order to make a judicious

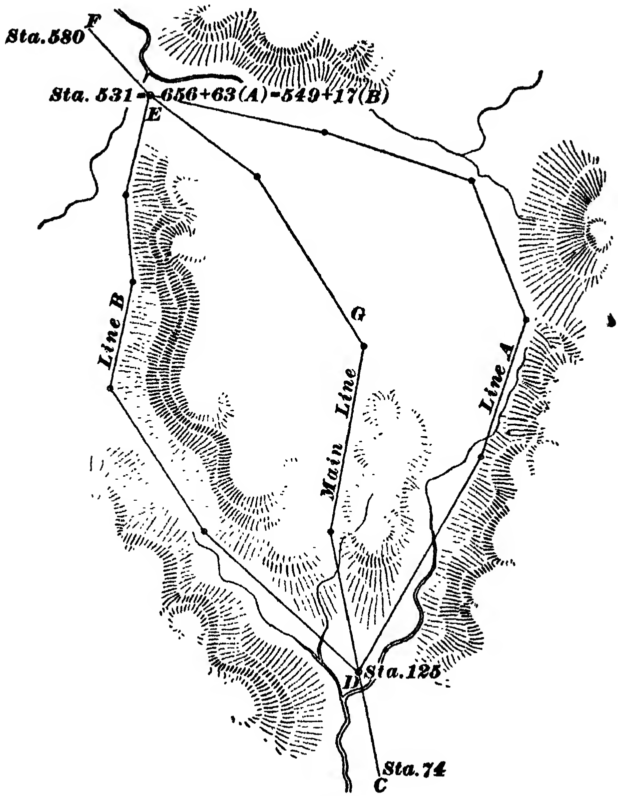


Fig. 13

choice. In some cases, the merits of the different lines are so evenly balanced that it is necessary to make location surveys and estimates of cost of some or all of them, so that a final decision may be made as to which line is most suitable.

62. In Fig. 13 is illustrated a case where two spur lines have been surveyed, connecting the same two points on the

main line. The main line is represented by CGF, on which the stations are numbered continuously from C to F. The spur line A begins at Sta. 125, and the numbering is carried continuously from D to the point where line A joins the main line at E. This point, which is common to both lines, is at Sta. 531 of the main line, and also at Sta. 656 + 63 of line A. Such a junction point between two lines is called an **equality station**; it is entered in the notes in the form of an equation as follows:

Sta. 531 = 656 + 63 line A

In this case, the stations on line B, which begins at D and ends at E, the same as line A, are also numbered continuously from D to the junction at the common point E. The station at E on line B is 549 + 17; this is recorded in the notes as follows:

Sta. 531 = 549 + 17 line B

In marking the station stakes on a spur line, the letter designating the line should be marked on each stake, just after the number of the station. For example, the stake at Sta. 625 on line A would be marked "625 A"; similarly, the stake at Sta. 510 on line B would be marked "510 B."

THE PRELIMINARY ESTIMATE

63. General Character.—After the preliminary survey is finished, an estimate should be made of the probable cost of the completed road. Sometimes, no estimate of cost is made until after the location is completed and the final grades are established. Usually, however, the estimate is based on the preliminary survey, since it is frequently necessary to estimate the cost of alternative lines in order to decide which line is most advantageous to construct. In either case, such an estimate is called a **preliminary estimate.**

In making a preliminary estimate, great accuracy is not necessary, and no time should be wasted in useless refinements of calculation. The estimate should be high enough to cover all probable cost, and a liberal allowance should be made to cover unforeseen contingencies that may develop

during construction. It is a common fault of engineers to underestimate the cost of a projected road. Most experienced engineers make it a rule to add 10 per cent. to a preliminary estimate in order to provide for contingencies.

64. Earthwork.—In estimating for earthwork, the amount of excavation and embankment is usually calculated from the center heights as shown on the profile. The cut or fill may be assumed to begin or end at the nearest half station, as at *A*, Fig. 14. This method is somewhat inexact, but it is close enough for this purpose. The prisms are supposed to begin in the middle of one station and extend to the middle of the next station, and the center heights are taken at the full stations. In Fig. 14, the vertical broken lines represent the limits of successive prisms, and the vertical solid lines are at the full stations.

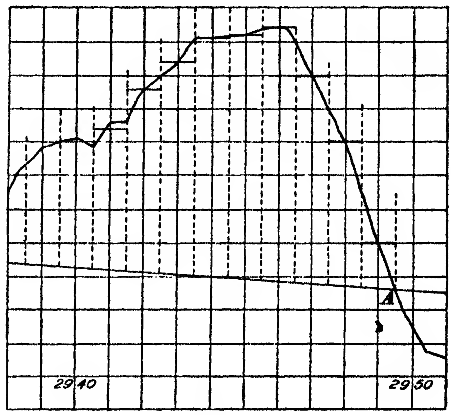


FIG. 14

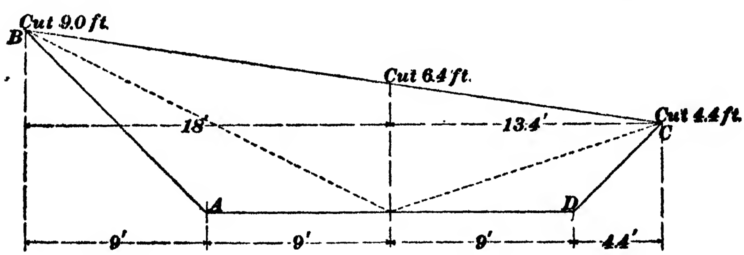


FIG. 15

Earthwork quantities may be taken from a table of level cuttings, except where the transverse slope of the ground exceeds 10° from the horizontal, in which case a suitable allowance should be made for the slope. The use of a table of level cuttings assumes that the cross-section surfaces are

level, and the areas are calculated from the center cuts and fills. Let Fig. 15 represent the actual cross-section at a given station, and Fig. 16 the cross-section based on the center cut. The area of the section *ABCD* in Fig. 15, calculated from the actual cross-section, is 160.78 square feet. The area of the section *A' B' C' D'* in Fig. 16, calculated from a level section, with the same center cut, viz., 6.4 feet, is 156.16 square feet, giving a discrepancy of 4.62 square feet; that is, the area of the section, calculated by level cuttings, is 4.62 square feet less than the area calculated from the actual cross-sections. This deficiency is about 3 per cent., but where the slope is very steep the difference increases rapidly. As it is the usual custom to add 10 per cent. to the estimated cost, such addition will generally cover any deficiency resulting from table calculations.

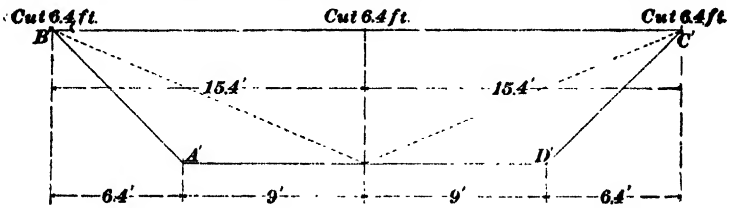


FIG. 16

Where time is not an object, it is good practice to take the slopes with a clinometer and plat them on cross-section paper. The estimate thus obtained will be a close approximation to the actual quantities handled in the work of construction.

For work in the northern and middle American states, the following rates of slope are standard: for embankments, $1\frac{1}{2}$ horizontal to 1 vertical; for earth cuts, 1 horizontal to 1 vertical; and for rock cuts, $\frac{1}{4}$ horizontal to 1 vertical. In the western and southern states, it is the usual custom to give to cuts the same slope as to embankments, viz., $1\frac{1}{2}$ horizontal to 1 vertical.

65. Trautwine's "Engineers' Pocketbook" contains complete tables of level cuttings for standard widths of roadway, both single and double track. The slopes are given for earthwork, both excavation and embankment. The

quantities are calculated for sections 100 feet apart. If the sections are taken at intervals of less than 100 feet, the quantities will be proportionally less. Table I is a part of the table given in Trautwine's book for single-track excavation, roadway 18 feet wide, slopes 1 horizontal to 1 vertical.

The use of this table is as follows: Suppose that the center cut at Sta. 10 is 1.5 feet and the center cut at Sta. 11 is 3 feet. The sum of these two center cuts is $1.5 + 3.0 = 4.5$ feet. The mean or average center cut for these stations is, therefore, $4.5 \div 2 = 2.2$ feet, nearly.

Referring to the table, we find, in the column headed Depth of Cut, the figure 2, and on the same horizontal line, under the column headed .2, we find 164.6, which

TABLE I

TABLE OF LEVEL CUTTINGS

Depth of Cut Feet	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	Cubic Yards	Cubic Yards	Cubic Yards	Cubic Yards	Cubic Yards	Cubic Yards	Cubic Yards	Cubic Yards	Cubic Yards	Cubic Yards
0	0	6.7	13.5	20.3	27.3	34.3	41.3	48.5	55.7	63.0
1	70.4	77.8	85.3	92.9	100.6	108.3	116.1	124.0	132.0	140.0
2	148.1	156.3	164.6	172.9	181.3	189.8	198.4	207.0	215.7	224.5

is the number of cubic yards of material to be excavated between Sta. 10 and Sta. 11.

The quantities are given for center cuts from .1 foot to 60 feet. For cuts greater than 60 feet, the quantities are calculated for each ½ foot to 80 feet, and after that for whole feet.

66. The character of the material to be excavated is largely a matter of conjecture. The notes taken by the locating engineer and the topographer concerning the surface formation, rock outcrops, etc. will usually be of considerable assistance in making the classification. In many cases, however, the appearance of the surface of the ground does not afford a true indication of the material below. Where it is

required to determine, with considerable accuracy, the nature of the material that is likely to be encountered in cuts, soundings or borings are made to the required depth below the surface. Soundings in earth are made with an iron or steel sounding rod of suitable length and having its lower end sharpened to a point. A good form of sounding rod consists of a round steel rod from $\frac{3}{8}$ to $\frac{1}{2}$ inch in diameter and from 6 to 10 feet in length. Borings can be made with an ordinary auger from $1\frac{1}{2}$ to 2 inches in diameter, having a stem or shank of suitable length with a wooden handle attached to its upper end.

67. Culverts.—In estimating the quantity of masonry for culverts, it is a good plan to use a diagram or table giving the volume of masonry in any standard type of culvert for embankments having a given width of roadbed, for given center heights. It is usually safe to base the estimate for a given culvert on the greatest center height, as the culvert will be built at or near the deepest part of the embankment. This rule is applicable to a pipe culvert in estimating the amount of pipe required for a given center height of fill.

68. Bridges, Trestles, Piers, and Abutments.—The volume of masonry required for bridge piers and abutments can be tabulated or expressed by a diagram for different heights. Then, for any given height, the quantity of masonry can be taken direct from the table or diagram. In estimating for timber trestles or bridges, the amount of timber required for the caps and the floor system is constant per unit of length, and may be taken at a given amount per running foot, regardless of the height of the structure. The length of the posts and the bracing will vary according to the height of the trestle, and the timber required for them is estimated according to the center height. Piling is estimated according to the number of linear feet of piles required. Timber used in bridges or trestles is estimated by the thousand feet, board measure. Wooden bridges of moderate span are sometimes estimated at a fixed price per

thousand feet, board measure, for the timber required, and a fixed price per pound for iron for bolts, spikes, and washers; usually, however, a special estimate is made for each bridge. In making estimates for iron or steel viaducts or bridges, it is customary to make a special estimate for each structure.

69. Form of Estimate.—The quantities of earthwork and other materials having been computed, they should be tabulated for the complete estimate. A complete preliminary estimate gives, in detail, the approximate quantities of all material to be used or handled in the work of construction, as well as the probable cost of such work. The different items entering into the estimate are usually classified according to their character, and prices are given according to the various units of measurement employed.

Under the heading of earthwork is included all excavation and embankment. Excavation is usually classified as earth, loose rock, or solid rock. Where different kinds of material are found, other classifications are sometimes used; as, for example, hard pan, gravel, etc. A good form for a preliminary estimate for a projected railroad is shown below.

ESTIMATE OF COST—*A* & *B* RAILROAD

Clearing 625 acres at $20 per acre		$ 12500
Earth excavation:	900,000 cu. yd. at 17c.	153000
Loose-rock excavation:	300,000 " " " 40c.	120000
Solid-rock excavation:	200,000 " " " 80c.	160000
Overhaul, exceeding 600 ft.: 300,000 cu. yd. at 1c.		3000
Borrowed embankment: 80,000 cu. yd. at 17c.		13600
Piling: 12,000 lin. ft. at 25c.		3000
Framed trestles: 300,000 ft. B. M. at $35 per M.		10500
First-class masonry:	2,800 cu. yd. at $12	33600
Second-class masonry:	4,200 " " " 8	33600
Box culvert masonry:	2,300 " " " 5	11500
Dry-rubble masonry:	2,600 " " " 4	10400
Concrete masonry:	3,000 " " " 6	18000
Riprap:	2,000 sq. " " 1.50	3000
Cast-iron pipe culverts: 40,000 lb. at 3c.		1200
Vitrified " "	1,800 lin. ft. at 1.50	2700
Total, exclusive of bridges and track		$589600
Add 10 per cent.		58960
Total cost for grading and trestles		$648560

LOCATION

70. Definition.—In general, **location** is the operation of fitting the line to the ground in such a manner as to secure the best adjustment of the alinement and grades, consistent with an economical cost of construction. The term *location* is also applied to the position of the line on the ground, "the line" being always understood to be the center line of the road.

71. Methods of Location.—There are two general methods employed for making a road location. The first method is used in ordinary country, where no topography party has been employed on the preliminary survey, the topographical features being shown by means of sketches drawn by the chief of party and the transitman in their notebooks. The preliminary line is then used, either as a base from which to project a location on the ground or as a guide from which to study the ground with a view of selecting a suitable location. In either case, the tangents are laid, run to their intersections, and then connected by proper curves, all the work being done directly on the ground.

The second method of location is usually employed in a rough country, where complete topographical notes have been taken on the preliminary survey. A complete topographical map is first drawn, and the location is then projected on the map. This **paper location,** as it is called, requires considerable skill and much study; it is sometimes made by the chief engineer himself. If a careful preliminary survey has been made, the location will vary but little from the preliminary line, and the latter line is treated as an approximate location from which the final location can be platted. Which method to use depends to a great extent on local conditions of topography. The second method, however, is generally preferred.

PAPER LOCATION

72. Advantages of Paper Location.—As already stated, the location may be made on the ground, without the intervention of maps, but this method is seldom used except in a smooth level country where a straight line is the best location. In a region where the ground is broken and hilly, this method of direct location tends to follow too closely the variations in the surface, and generally requires excessive curvature. The use of a contour map affords a much larger view of the country than is possible on the ground, so that a better adjustment of the line can be made and consequently a much better alinement secured.

73. General Description of the Method.—When the location is projected on the map, the line is laid down on the contour maps, which contain all the information accumulated by the preceding surveys. The grade for each station is taken from the preliminary profile, and marked on the contour maps opposite the corresponding station. This is readily done, as the contours are but 5 feet apart, and intermediate elevations can easily be estimated. These grade points are commonly marked by small red dots enclosed in small circles of the same color; they show where the plane of the grade would cut the surface of the ground. A piece of fine thread is then stretched, covering as many of these points as possible, and a pencil line drawn along the thread. This pencil line will locate a tangent on the map. In the same way, any number of tangents may be located.

74. The Curved Protractor.— **A curved protractor** affords a quick and convenient method of fitting curves to the tangents. An instrument of this kind is shown in Fig. 17; it consists of a series of curves of different radii, drawn on a sheet of some transparent material, such as horn or mica, and to the same scale as the contour map. A curve protractor suitable for field or office use can be made in the following manner:

On a piece of tracing cloth of suitable size, draw two lines at right angles to each other, and use their intersection as a

center from which to draw concentric semicircles, to the same scale as was used for the map—say 200 feet per inch. Begin with an 8° curve, and draw the successive curves at intervals of 30 minutes up to 15°, or higher, if required. Next reverse the sheet and draw the curves of larger radii, at intervals of 30 minutes between 8° and 1°. These curves need not be concentric, but their centers should be on the same vertical line. The resulting figure will be similar to that shown in Fig. 17.

Such a curve protractor can be readily drawn with an ordinary set of drawing instruments; it can be rolled up in a map or profile and carried into the field without injury. When in use, it is laid on the contour map at or near the

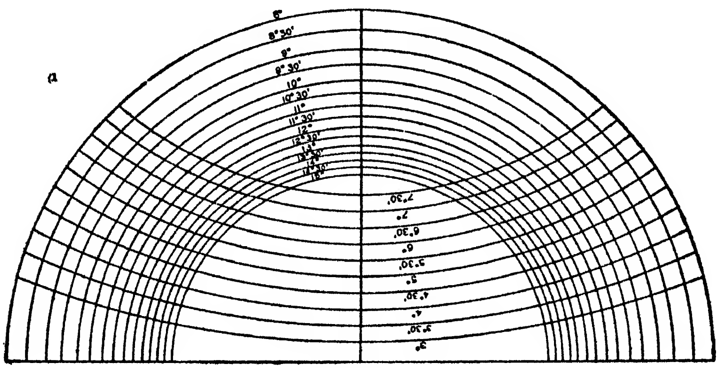


FIG. 17

junction of the two tangents that are to be connected with a curve. The curve protractor is then shifted until a suitable curve is found that will fit the topography and will close the angle between the tangents as required; the P. C. and the P. T. are then marked on the tangents at the extremities of the connecting curve. Having determined the degree of curve to be used for connecting the tangents, the angle of intersection can be measured by a protractor, or calculated if preferred, and the tangent distances are then scaled off. Great accuracy in measuring the intersection angles on the map is not essential, since the projected tangents when run out on the ground will not always correspond exactly with their positions on the map.

75. The Adjustment of Gradients.—The adjustment of the grade line requires considerable skill and much sound judgment. Such work should be done by the locating engineer, since he is familiar with the local conditions and the general character of the topography along the line. Grade lines are usually projected in such a manner as to equalize as far as possible the quantities of excavation and embankment; this, however, is not a fixed rule. Local conditions—such as crossing under the tracks of another railroad, or beneath a street or highway, or over a ridge or summit on the maximum gradient—usually require excess of excavation over embankment. In a flat swampy region, the embankment should be built high enough to form a solid,

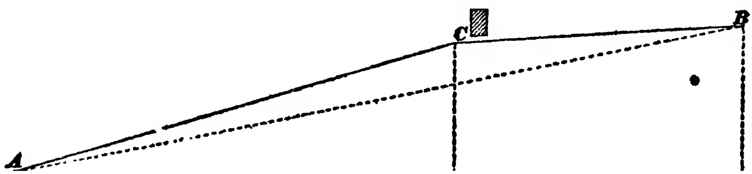


FIG. 18

well-drained roadbed; in such a case, the embankment will exceed the excavation.

Stopping places for trains, such as stations, water tanks, etc., should never be located at the foot of a heavy gradient; they should preferably be located where the grade is level or nearly level. If a stopping place is necessary on a long, heavy gradient, it is usually preferable to break the grade, as at C, Fig. 18, and introduce a short piece of light grade, as CB, than to have a uniform heavy grade, as AB. The gradient AC is steeper than the original gradient AB, but this arrangement is preferable, provided that the portion from A to C is within the limit of the maximum gradient used on the road.

76. Example of Paper Location.—The platting of a paper location is illustrated in Fig. 19. Here the line follows the valley of Bear River, and the gradient is determined by the slope of the stream. The gradient adopted is

.5 per cent., or .5 foot per station. The preliminary line is shown dotted, and the located line is drawn full.

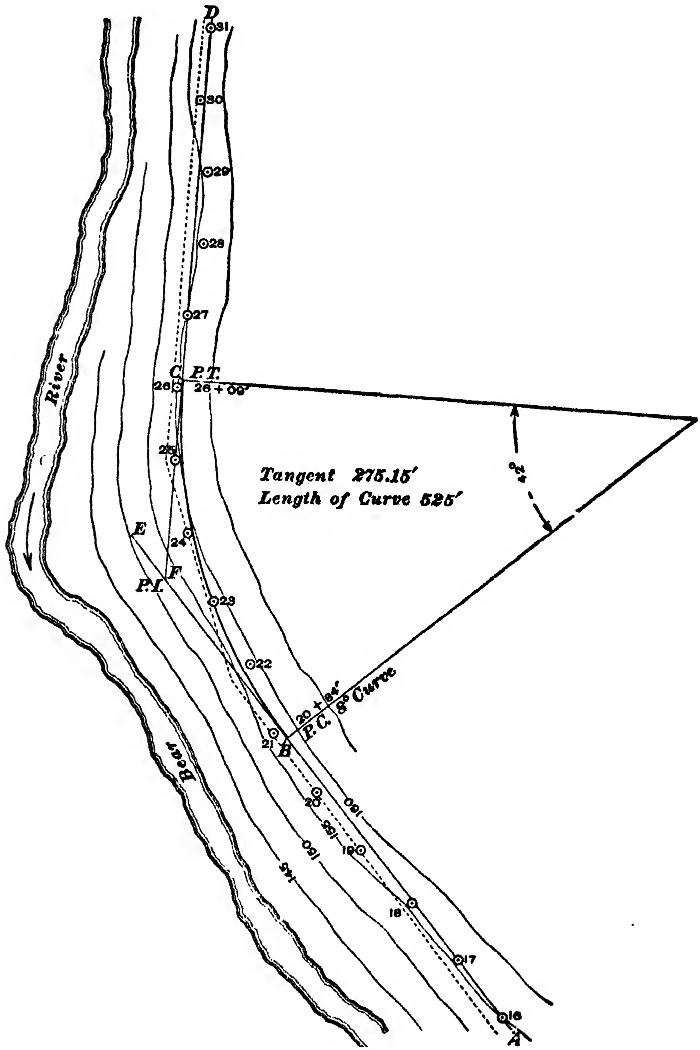


FIG. 19

Let the grade elevation for Sta. 16 be 155 feet; the grade elevation for Sta. 17 will, therefore, be 155 feet + .5 foot = 155.5 feet. The grade elevation for Sta. 18 will be

155.5 + .5 = 156 feet. By the same process, the grade elevation is found for each station shown in the plat; and the required grade elevation for each station is designated on the contour map, opposite the corresponding station of the preliminary line, by a small dot enclosed in a circle. A line joining the points thus designated will be the grade contour, or the line where the required gradient meets the surface of the ground. It is not practicable, however, to follow the grade contour exactly with the located line; but the location should be as close to the grade contour as the conditions of curvature and the nature of the ground will permit. The tangents *AB* and *CD* are projected so as to conform as closely as practicable to the grade contour; they are produced until they intersect at a point *F*, which is called the P. I. The exterior angle *EFD*, or the angle of intersection, which is usually written *I*, is then measured with a protractor. In order to determine what curve will connect the two tangents and fit the ground to the best advantage, a curve protractor is used in the manner previously described. If a curve protractor is not available, a pair of compasses may be used; they are set to different radial lengths and tried until the best curve is found. When spiral or transition curves are used, an offset is left at each end of the circular curve, between the curve and the tangent. Each offset should be long enough to admit of the use of a spiral curve of the required length.

77. Field Notes From the Paper Location.—After the located line has been projected on the contour map, the engineer should make careful notes of the required distances between the preliminary line and the projected location at suitable points. In taking notes from the paper location for use in the field, the points fixing the positions of the several tangents are carefully scaled from fixed points on the preliminary line, so that, in case it is necessary to swing a terminal tangent, the desired position for the tangent can be readily determined by measurement from some fixed point. The field notes for the location shown in Fig. 19 can be written as follows:

Set hubs 20 feet right of Sta. 16 and 10 feet right of Sta. 22; pass tangent through the two points thus found, and produce tangent to a point opposite Sta. 24. Set hubs 9 feet right of Sta. 25 and 10 feet right of Sta. 31; pass tangent through the two hubs, and produce to an intersection with first tangent. Measure the angle of intersection, calculate tangent distances from P. I. and set hubs for P. C. and P. T. of an 8° curve to connect the two tangents.

This form of notes is suitable for field use when the country is open and the tangents are to be run to their intersection. In case it is not required to produce the tangents to their intersection, the following form of notes may be used:

Set hubs 20 feet right of Sta. 16 and 10 feet right of Sta. 31. Pass tangent through these points, and make Sta. 20 + 84 = P. C. of 8° curve to the right for 42°. At P. T. of this curve, Sta. 26 + 9, turn tangent, which should pass 10 feet right of Sta. 31 of the preliminary line. If the terminal tangent misses the required position, lengthen or shorten the curve, as the case may be, so as to throw the tangent in the required position.

The engineer, in making a location, should bear in mind that the main object of the survey is to get the located line on the best ground, and that this point is more important than a close agreement with the measurements of the preliminary line. It is not to be expected that the measurements of the two lines will agree very closely; the preliminary line should be used only as a guide to the general position of the location.

78. Curvature.—There is no fixed rule for limiting curvature, but for a permanent track it is desirable to have the curvature as easy as possible. If construction funds are limited, and it is required to economize on the cost of the road, sharp curvature may be used, which can be eliminated or improved at a later time, when the business of the road increases sufficiently to justify the work. For all ordinary traffic conditions, it is good practice to use such

curves as will best conform to existing topographical conditions. Any curve up to 10° will be no obstacle to a speed of 35 miles per hour, the average speed of passenger trains. This affords a range in curvature that will meet the requirements of most localities.

In Fig. 20 is illustrated a case where sharp curvature is used advantageously to reduce the cost of construction. The line follows the course of a stream in a narrow valley, whose sides are steep and rough. Unless the prospective business is large and the railroad company is financially strong,

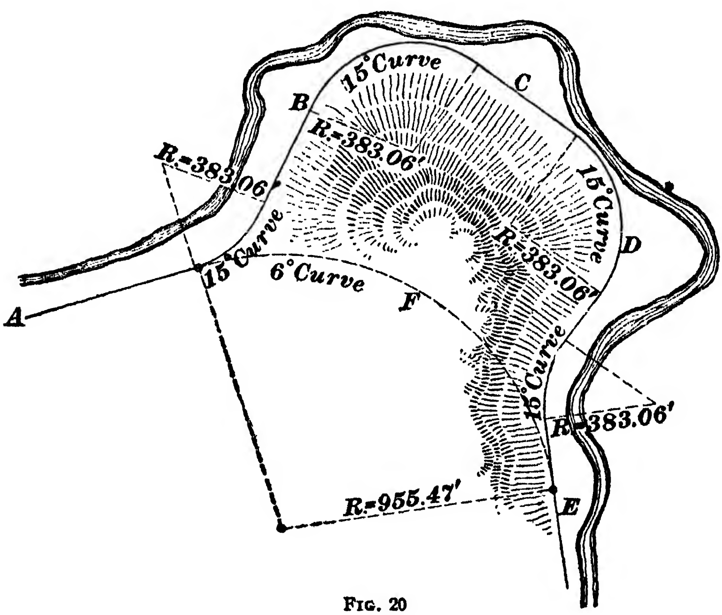


FIG. 20

it will be a much better policy to build the line $ABCDE$, using curves as high as 15°, and reducing cost to a minimum, than to build the line AFE, giving a single curve of 6°, but requiring a heavy rock cut at F, or perhaps a tunnel at that point. The line AFE is always possible, and when the road has built up a paying traffic and finances are easy, the cut or tunnel at F can be made without interfering in any way with traffic, and in all probability the work can be done

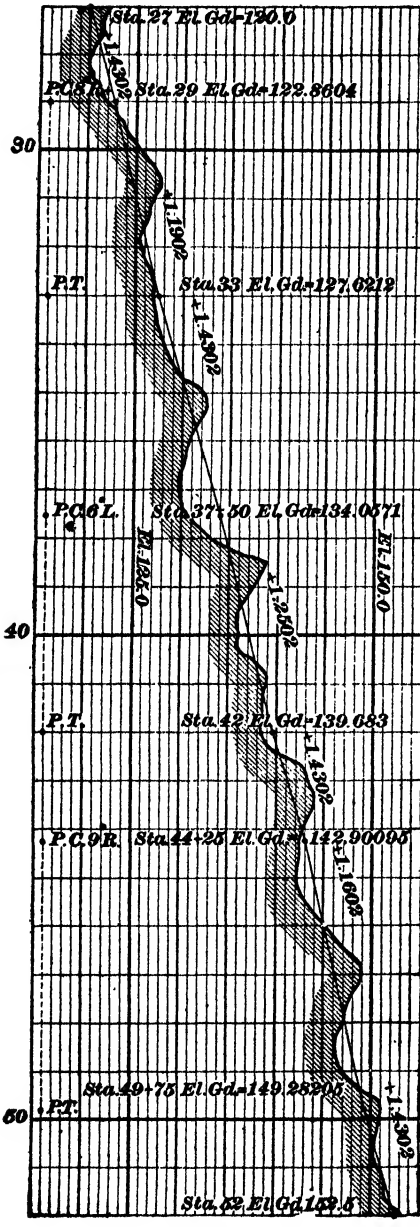


FIG. 21

more cheaply than was possible at the time the temporary line *ABCDE* was built.

79. Compensation for Curvature.—The effect of curvature on a railroad line is to cause a resistance to the movement of trains; such resistance is assumed to vary inversely as the length of radius or directly as the degree of curvature, although it is readily demonstrated that this law is far from accurate. When a curve occurs on a gradient, the effect of the curve resistance on ascending trains is practically the same as increasing the gradient. It is customary in fixing the final grades to lighten the grade on a curve an amount sufficient to offset the resistance due to the curvature. This operation is called **compensating for curvature.** The usual rate of compensation for curvature is .03 to .05 foot per hundred feet per degree

of curvature. For example, where the maximum gradient on tangents is 1 per cent., the maximum gradient on a 6° curve, allowing a compensation of .03 foot per degree, would be $1 - (.03 \times 6) = .82$ per cent. If a compensation of .05 foot per degree were made, the grade on a 6° curve would be $1 - (.05 \times 6) = .70$ per cent.

80. Final Grade Lines.—The establishing of **final grade lines** is illustrated in Fig. 21, where the uncompensated grade is 1.3 per cent., and the compensation for curvature, as shown in the final grade line, is .03 foot per degree. The location notes for this line are as follows:

Stations	Intersection Angles
52 + 00	End of grade
49 + 75 P. T.	
44 + 25 P. C. 9° R.	49° 30′
42 + 00 P. T.	
37 + 50 P. C. 6° L.	27° 00′
33 + 00 P. T.	
29 + 00 P. C. 8° R.	32° 00′
27 + 00	Beginning of grade

The profile is made to standard scales; namely, horizontal, 400 feet = 1 inch; vertical, 20 feet = 1 inch. The elevation of the grade at Sta. 27 is fixed at 120 feet, and at Sta. 52, at 152.5 feet, giving between these stations an actual rise of 32.5 feet and an uncompensated grade of 1.3 per cent. These grade points are marked on the profile with small circles. The total curvature between Sta. 27 and Sta. 52 is 108½°. The resistance due to each degree of curvature being taken as equivalent to an increase of .03 foot in grade, the total resistance due to 108.5° is equivalent to $.03 \times 108.5 = 3.255$ feet additional rise between Sta. 27 and Sta. 52. Hence, the total theoretical grade between these stations is the sum of 32.5 feet, the actual rise, and 3.255 feet due to

curvature, or 35.755 feet. Dividing 35.755 by 25, the number of stations in the given distance, we have 35.755 ÷ 25 = + 1.4302 feet, as the grade for tangents on this line. The starting point of this grade is at Sta. 27. The P. C. of the first curve is at Sta. 29, giving a tangent of 200 feet = 2 stations, As the grade for tangents is +1.4302 feet per station, the rise in grade between Stas. 27 and 29 is 1.4302 × 2 = 2.8604 feet. The elevation of grade at Sta. 27 is 120 feet, and the elevation of grade at Sta. 29 is 120 + 2.8604 = 122.8604 feet, which is recorded on the profile as shown in the diagram, with the rate of grade, viz., +1.4302, written above the grade line. The first curve is 8°, and, as the compensation per degree is .03 foot, then, for 8°, or a full station, the compensation is .03 foot × 8 = .24 foot. The grade on the curve will, therefore, be the tangent grade minus the compensation, or 1.4302 − .24 foot = +1.1902 feet per station. The P. C. of this curve is at Sta. 29, the P. T. at Sta. 33, making the total length of the curve 400 feet = 4 stations. The grade on this curve is +1.1902 feet per station, and the total rise on the curve is 1.1902 × 4 = 4.7608 feet. The elevation of the grade at the P. C. at Sta. 29 is 122.8604; hence, the elevation of grade at the P. T. at Sta. 33 is 122.8604 + 4.7608 = 127.6212 feet, which is recorded on the profile together with the grade, viz., +1.1902, written above the grade line. The P. C. of the next curve is at Sta. 37 + 50, giving an intermediate tangent of 450 feet = 4.5 stations. The grade for tangents is +1.4302 feet per station; hence, the total rise on the tangent is 1.4302 × 4.5 = 6.4359 feet. Adding 6.4359 feet to 127.6212 feet, the elevation of grade at Sta. 37 + 50 is found to be 134.0571 feet, which is recorded on the profile, together with the rate of grade for tangents.

The next curve is 6°, and the compensation in grade per station is .03 foot × 6 = .18 foot. The grade on this curve will, therefore, be 1.4302 − .18 = 1.2502 feet per station. The length of the curve is 450 feet = 4.5 stations, and the total rise in grade on this curve is +1.2502 feet × 4.5 = 5.6259 feet. The elevation of the grade at Sta. 37 + 50, the P. C. of the curve, is 134.0571. The elevation of the grade

at Sta. 42, the P. T., is therefore 134.0571 + 5.6259 = 139.683 feet, which is recorded on the profile together with the rate of grade on the 6° curve, viz., +1.2502. The P. C. of the next curve is at Sta. 44 + 25, giving an intermediate tangent of 225 feet = 2.25 stations. The total rise on the tangent is, therefore, 1.4302 × 2.25 = 3.21795 feet. The elevation of grade at the P. T. at Sta. 42 is 139.683; therefore, the elevation of grade at Sta. 44 + 25 is 139.683 + 3.21795 feet = 142.90095 feet, which is recorded on the profile together with the grade, +1.4302.

The last curve is 9°, and the compensation in grade per station is .03 foot × 9 = .27 foot. The grade on this curve is, therefore, 1.4302 − .27 = 1.1602 feet per station. The length of the curve is 550 feet = 5.5 stations, and the total rise on the curve is 1.1602 × 5.5 = 6.3811 feet. The elevation of grade at Sta. 44 + 25, the P. C. of the 9° curve, is 142.90095; hence, the elevation of grade at the P. T., at Sta. 49 + 75, is 142.90095 + 6.3811 = 149.28205 feet, which is recorded on the profile together with the grade, +1.1602. The end of the line is at Sta. 53, giving a tangent of 225 feet = 2.25 stations. The rise on this tangent is 1.4302 × 2.25 = 3.21795 feet, which is added to 149.28205, the elevation of the P. T. at Sta. 49 + 75. The sum, 152.5 feet, is the elevation of grade at Sta. 52.

The sum of the partial grades should equal the total rise between the extremities of the grade line. The points where the changes of grade occur are marked on the profile in small circles, which are connected by fine lines representing the grade line. These points of change are projected on a horizontal line at the bottom of the profile. The portions of this line that represent curves are dotted, and the portions that represent tangents are drawn full. The points of curve P. C. and P. T. are marked in small circles on this horizontal line, and are lettered as shown in the diagram.

Where the grades are light and the curves have large radii, there will be no need of compensation for curvature. Where the grades exceed .5 per cent. and the curves 5°, compensation should be made.

LOCATION FIELD WORK

81. Work of the Locating Party.—The operation of laying out the line of the road on the ground is called a **location survey.** The organization of the survey party is practically the same for location as for the preliminary survey, except that usually no topography party is required on location, and a back flagman is added to the transit party.

The locating engineer projects the location either by making complete alinement notes from the contour map, to be followed in the field, or by selecting suitable points on the ground through which to run the location. In either case, he should accompany the party in the field, and exercise a general supervision over the work, keeping constantly on the lookout for possible improvements in the line. He should take careful notes of all stream crossings, and make rough estimates of the drainage areas of the streams crossed, to serve as a guide in estimating the areas of the various openings required, and also to assist in determining the character of bridges to be used. He should note the nature of the ground over which the line passes, and determine, as far as possible, the composition of cuts, by means of a sounding rod or an auger, if there is doubt as to the existence of rock.

82. The transitman on location should keep full notes of the alinement and also of such topography as is required. He should check all computations for deflections on curves, noting both the magnetic and the calculated bearings of all tangents. The bearing of each tangent is determined, from that of the tangent next preceding, by the total deflection angle contained in the connecting curve. The bearing of a course at the beginning of a survey is first determined by the needle or by comparing it with the bearing of a line whose direction is known; the bearing of each successive course or tangent is then determined by calculation. The needle is not used on location, except as a check on the bearings of the tangents, and as a means of determining the bearings of roads, fences, land lines, etc.

83. On location, a back flagman is required to give back sights to the transitman. His duty consists in holding the transit rod in a vertical position on the required point for each sight.

84. Stakes are placed at all 100-foot stations, at intervals of 50 feet on curves, and at substations. Turning points, such as the P. C. or P. T. of a curve, or intermediate transit points, are marked by hubs or plugs driven flush with the surface of the ground, the exact point being marked by a nail or tack driven in the top of the plug. At each transit point, a witness stake should be driven about 18 inches to the left of the line and facing the hub. If the transit point is at a full station, the number of the station is marked on the witness stake; if at a substation, the number of the next preceding station and the plus should be marked on the witness stake. If, for example, a hub is set on line 60 feet from Sta. 101 and between Stas. 101 and 102, the witness stake for the hub is marked 101 + 60.

85. The level party will have more time for their work on location than on the preliminary survey, since the progress of the transit party is necessarily slow on location. The elevations at stations and substations should be carefully determined, and plus distances for intermediate readings should be measured with a tape. In some cases, small round pegs, about $\frac{3}{4}$ inch in diameter and from 4 to 6 inches long, are driven at each station; they are driven flush with the ground, and the rod reading for the station elevation is taken on the top of the peg. Bench marks on location should be placed on the edge of the right of way, in order that they may be safe from disturbance by clearing or other work during construction. Bench marks should be established at intervals of from 1,200 to 1,500 feet; they should preferably be made at or near the ends of long cuts or embankments, and at points on the line where important structures, such as culverts, trestles, abutments, etc., are to be built.

86. Topography notes on location, if taken at all, are usually taken by the transitman or the chief of party. If the

preliminary survey has been well made, there will usually be little need for the taking of much topography during the location survey.

87. The locating engineer, the transitman, and the leveler should all make full notes on location concerning the details of topography and of local conditions along the line. Where a stream of considerable size is crossed, careful cross-sections should be made by means of soundings, as described in *Hydrographic Surveying*. Borings or soundings should also be made at suitable places on the banks or in the bed of the stream, in order to ascertain the depth to rock or hard pan, and to determine the nature of the foundations for bridge piers and abutments. Inquiries should be made concerning the amount of rainfall, the height and duration of floods, etc.; and all possible information concerning the watercourses should be obtained that may be of value in proportioning the sizes of bridge openings and waterways. Land and property lines are located by noting the station or plus where they cross the survey, and also by measuring the angle made by the land line with the line of the survey.

88. Tangents.—If the country is open, the tangents are run to their intersection, and the angle of intersection is measured with the transit. The tangent distances are then measured both ways from the P. I. (point of intersection), and hubs are set for the P. C. and the P. T. of the required curve.

If the country is heavily timbered or is rough and rugged, the tangents are not usually run to their intersection. In such cases, the notes of the paper location are followed out by measurements from the preliminary line. Each tangent is run to the P. C. as projected, the projected curve is run in, and the next tangent is started at the P. T. of the curve. In case the curve does not terminate exactly as calculated, the terminal tangent can be swung into the required position by lengthening or shortening the curve.

89. Sections.—The line is divided into lengths of about 1 mile each, called **sections**, which are numbered in regular

order, the first mile of the line being section 1, the second mile section 2, and so on. At the divison points, that is, where one section ends and another begins, posts are set up with boards attached, facing in both directions, with the numbers of the sections toward which they face written in large figures. (See Fig. 22.)

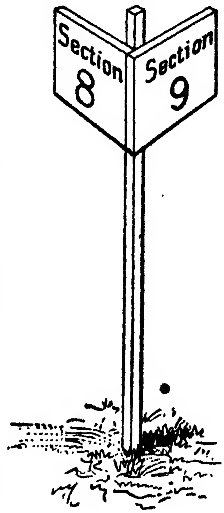


Fig. 22

The section boards enable one to readily locate any particular part of the line.

90. Field Profiles.—The profile should be kept platted as fast as the line is located, in order that the chief of party may know how nearly the actual profile approximates the theoretical one (the one that is made from the paper location) and what changes may be necessary.

FINAL LOCATION

91. After the right of way has been cleared, affording an unobstructed view of the ground, it will frequently be seen that slight changes in the located line will greatly reduce the cost of construction; and not until such changes are made will the engineer have made the **final location.**

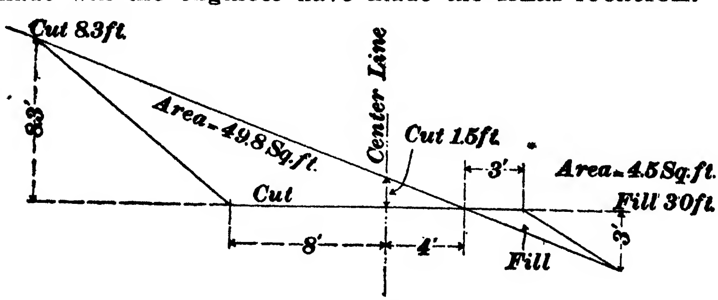


Fig. 23

None but experienced engineers can understand how a slight change in location, especially on a side-hill line, can so greatly affect cost; and it is first cost that generally determines the success or failure of the enterprise.

Figs. 23 and 24 may serve as illustrations of a bad and a good location, respectively. Fig. 23 shows a defective location, which can readily be avoided by a little conscientious work and common sense. This location may be replaced by that shown in Fig. 24, which is far superior.

Side hills afford an opportunity for almost the cheapest form of construction. A **grade line**—that is, a center line coinciding with the surface of the ground, as in Fig. 24—can, unless rock is encountered, be graded with pick and shovel alone, the men casting the material taken from the cut directly into and making the fill. The area of the cut in Fig. 23 is 49.8 square feet, while the area of the fill is but 4.5 square feet, leaving an excess of excavation of 45.3 square

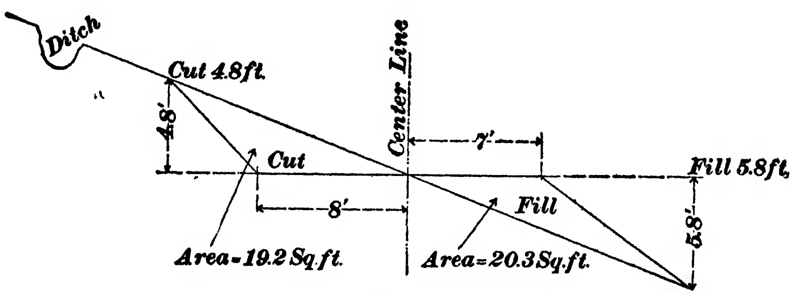


Fig. 24

feet, or ten times the area of the fill. There is no way by which this excess of material can be utilized; it must, therefore, be wasted, as has been the labor of excavating it. By moving the center line 4 feet to the right, the cross-section shown in Fig. 24 is obtained, in which the calculated areas of cut and fill are as follows: cut, 19.2 square feet; fill, 20.3 square feet—a difference of less than 1 square foot, with the excess on the right side, for a ditch should be made 4 feet from the top of the upper slope to prevent the washing down of the slope, and this material will more than equal the excess of the fill over the cut.

92. The Location Profile.—The profile of the located line should have the ground line drawn in India ink, shaded on the lower side with gray. The grade line should be drawn

in red ink or carmine; each change in the rate of grade should be marked by a small circle enclosing the grade point. The elevation of the grade line at each grade change and the rate of grade between successive changes should be expressed in figures. The bridging and the various openings should be plainly shown; the character of each bridge and opening should be designated; and the names of the different streams should be written on the profile. The nature of the country, whether open or timbered, should be stated. In some cases, estimates of earth work for the various cuts and fills are written on the profile, also the quantities of construction material required at the different bridge and culvert openings. The alinement is shown near the bottom of the profile, that portion of the line corresponding to tangents being drawn in full lines, and the curves represented by broken lines. The stations of the points of curve and tangency, as well as the terminal points of spirals, are properly marked and numbered.

93. Map of Final Location.—After the final location is made, a complete map of the line should be drawn. Such a map should show the alinement in detail, including the P. C. and P. T. of each curve, the degree of curvature, the terminal points of spirals, and all P. C. C.'s. The central angle of each curve should be given, and the correct bearing of each tangent should be written near the line. The map should also show the limits of the right of way, the positions and bearings of property lines, and the positions of known land corners, when they lie within the limits of the map. The names of property owners whose property is on or adjacent to the right of way, and complete details of local topography, including buildings and other structures, should be shown. The nature of the country and the character of the clearing should also be indicated. The center line is preferably drawn in red ink, and the right-of-way boundaries, the topography, and other details, in India ink. The map may be drawn on good Manila paper or on heavy mounted paper, as preferred. The map of the final location is usually

drawn continuously on a roll of paper of suitable size; but there is no fixed rule on this point, and sheets of convenient size may be used if preferred.

RIGHT OF WAY

94. The **right of way** is the strip of land that must be acquired for the construction of the road. Before construction can be commenced, the right of way must be secured. This matter is always attended with more or less difficulty. The standard width of right of way is 100 feet, though in some cases but 4 rods, or 66 feet, is adopted, with additional widths wherever needed.

Where the local needs for the road are great and the enterprise popular, much right of way is often donated, a nominal sum, usually one dollar, being paid as consideration. The ordinary mode of securing right of way, however, is by direct purchase. The company employs an agent specially fitted for this business, who makes the most advantageous bargains possible with the different owners. When there is failure to agree on price, a common alternative is to leave the question to three arbitrators; each of the parties to the transaction choosing one, and both parties agreeing on the third. Occasionally, an owner, taking advantage of the situation, attempts extortion, in which case the only recourse is to the law of eminent domain. Articles of condemnation are taken out and appraisers appointed by the court, who fix the amount of compensation. This process is always attended by expense, delay, and vexation, and should be only a last resort.

95. Right-of-Way Maps.—A careful survey is made of each separate piece of property bought for right of way or station grounds, and stone corners are established for future reference. These surveys should be platted in a "right-of-way" book in the same order in which they occur on the line, and a copy of the contract for the property, together with a description of it, should be written either

on the same page or on that adjoining the plat. The plat should specify content, boundaries, corners, and any information that may be of future use. A copy of the contract and a tracing of the plat are delivered to the person or persons from whom the property is bought.

VERTICAL CURVES

96. Definitions.—If the grade of the center line of track changes at any point, the two grade lines that intersect at this point form with each other an angle more or less

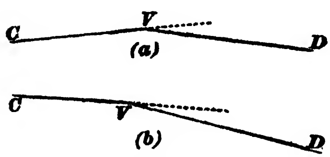


FIG. 25

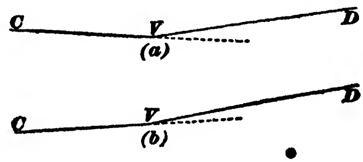


FIG. 26

abrupt. If this angle points upwards, it is called a **spur**; if it points downwards, it is called a **sag**.

The angles CVD in Figs. 25 and 27 are spurs; the angles CVD in Figs. 26 and 28 are sags. If either grade line is produced beyond the vertex of the angle, a spur will

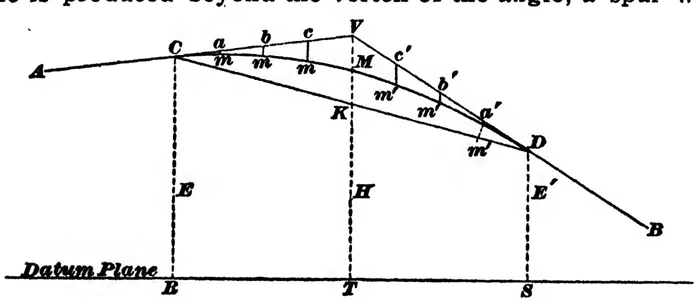


FIG. 27

evidently occur whenever the other grade line lies below the grade line that is produced (see Fig. 25); otherwise, a sag will occur (see Fig. 26). In either case, the angle must be rounded off by the introduction of a curve called a **vertical curve.**

In the following articles, a brief discussion of vertical curves will be given. Circular curves and spirals are treated in *Circular Curves* and *The Transition Spiral*, respectively.

97. Vertical Curve at a Spur.—If AV and BV, Fig. 27, are two grade lines meeting at V, a vertical curve CMD must be introduced joining these lines. Between C and D, the actual grade is established along the vertical curve CMD, instead of along CV and VD. The projections RT and TS of the distances VC and VD from the vertex to the points at which the vertical curve begins and ends are always chosen equal. If K is the middle point of the straight line CD, the vertical curve is always so chosen that it will bisect VK—that is, so that $VM = MK$.

98. Let E be the elevation of C, Fig. 27, E' that of D; and H that of V, so that $E = RC$, $E' = SD$, and $H = VT$. Then, for the elevation of K,

$$KT = \tfrac{1}{2}(CR + DS) = \tfrac{1}{2}(E + E')$$

and for that of M,

$$MT = \tfrac{1}{2}(TV + TK) = \tfrac{1}{2}\left(H + \frac{E + E'}{2}\right)$$

Subtracting the elevation of M from that of V, the remainder will be the distance VM from the vertex to the vertical curve:

$$VM = H - \tfrac{1}{2}\left(H + \frac{E + E'}{2}\right) = \tfrac{1}{2}\left(H - \frac{E + E'}{2}\right) \qquad (1)$$

The distance VM is called the **correction in grade** at the point V.

Vertical curves are always made parabolic. It is a property of the parabola that the correction in grade am at any point a is given by the equation,

$$am = VM \times \left(\frac{Ca}{CV}\right)^2 \qquad (2)$$

The distance $CV = VD$ is always made a whole number of stations; and, to simplify the work, the grade stakes a, b, c, etc. are so set that they divide the distance CV into a number of equal parts. The corrections in grade at points

a', b', and c' along $D\,V$ are equal to those for the corresponding stakes along $C\,V$. That is, if $C\,a = D\,a'$, then $a\,m = a'\,m'$; if $C\,b = D\,b'$, then $b\,m = b'\,m'$, etc.

EXAMPLE.—A +.4-per-cent. grade meets a −.5-per-cent. grade at Sta. 190, the elevation of which is 161.3 feet. If a vertical curve 400 feet long is inserted, what is the correction in grade and the corrected grade elevation at each station and half station?

SOLUTION.—In this example, $V\,C = V\,D = 200$ ft.
Elevation of C is $161.3 - 2 \times .4 = 160.5$ ft., $= E$.
Elevation of D is $161.3 - 2 \times .5 = 160.3$ ft., $= E'$.
Elevation of K is $\frac{1}{2}(E' + E) = \frac{1}{2}(160.5 + 160.3) =$ **160.4 ft.**
Elevation of V is $H = 161.3$ ft.
Substituting these values in formula **1**,

$$V\,M = \tfrac{1}{2}(161.3 - 160.4) = .45 \text{ ft.}$$

Since, for the first stake, $C\,a = 50$ ft. and $C\,V = 200$ ft., formula **2** gives

$$a\,m = \left(\frac{50}{200}\right)^2 \times V\,M = \frac{1}{16} \times .45 = .03 \text{ ft.} = a'\,m'$$

Similarly, $$b\,m = \left(\frac{100}{200}\right)^2 \times V\,M = \frac{1}{4} \times .45 = .11 = b'\,m'$$

$$c\,m = \left(\frac{150}{200}\right)^2 \times V\,M = \frac{9}{16} \times .45 = .25 = c'\,m'$$

The original and corrected grade elevations are as follows:

Station	188	+50	189	+50	190	+50	191	+50	192
Original elevation	160.5	160.70	160.90	161.10	161.30	161.05	160.80	160.55	160.30
Correction	.0	.03	.11	.25	.45	.25	.11	.03	.00
Corrected elevat'n	160.50	160.67	160.79	160.85	160.85	160.80	160.69	160.52	160.30

EXAMPLE FOR PRACTICE

Find the corrections in grade and the corrected elevations at stakes 50 feet apart, if the vertical curve is 400 feet long: grade of $C\,V$ = +.4 per cent.; of $V\,D$ = −.6 per cent.; elevation of V = 101.4 feet.

Ans. { Corrections in grade: .00, .03, .13, .28, .50, .28, .13, .03, and .00
Corrected elevations: 100.60, 100.77, 100.87, 100.92, 100.90, 100.82, 100.67, 100.47, and 100.20

---

99. Vertical Curve at a Sag.—If two grade lines, $A\,V$ and $V\,B$, Fig. 28, meet so as to form a sag, the vertical curve will evidently be wholly above both grade lines. Using the notation of the last article, the elevation of K will be $T\,K = \frac{1}{2}(E + E')$, as before, and the elevation of M,

$TM = \frac{1}{2}\left(H + \frac{E+E'}{2}\right)$. But in this case M is above V, and therefore the correction VM in grade will equal $TM - TV$; that is,

$$VM = \frac{1}{2}\left(H - \frac{E+E'}{2}\right) - H = \frac{1}{2}\left(\frac{E'+E}{2} - H\right)$$

The correction in grade at any point a will be given by formula **2**, Art. **98**, as before, but this correction is now to

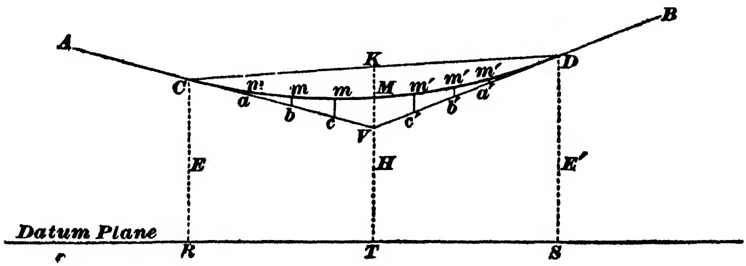


FIG. 28

be added to the old grade at a to obtain the corrected elevation.

EXAMPLE.—The grade of CV, Fig. 28, is -1.2 per cent.; that of VD is $+.6$ per cent., and the elevation of V is $+49.2$ feet. To find the corrections in grade and the corrected elevations at stakes 100 feet apart, if the length of the vertical curve is 600 feet.

SOLUTION.—The uncorrected grades are as follows:

ALONG CV	ALONG VD
At first stake, 52.8	At fifth stake, 49.8
At second stake, 51.6	At sixth stake, 50.4
At third stake, 50.4	At seventh stake, D, 51.0
At fourth stake, V, 49.2	

Therefore, $\frac{1}{2}(E + E') = \frac{1}{2}(52.8 + 51.0) = 51.9$

And, by the formula of this article,

$$VM = \frac{1}{2}(51.9 - 49.2) = 1.35 \text{ ft.}$$

Formula **2**, Art. **98**, may now be applied.

Correction in grade at first stake,

100 ft. from $C = \left(\frac{100}{300}\right)^2 \times 1.35 = \frac{1}{9} \times 1.35 = .15 =$ correction at fifth stake

Correction at second stake,

$\left(\frac{200}{300}\right)^2 \times 1.35 = \frac{4}{9} \times 1.35 = .60 =$ correction at fourth stake

The corrected elevations will be

At C	52.80 + .00 = 52.80
At second stake	51.60 + .15 = 51.75
At third stake	50.40 + .60 = 51.00
At fourth stake	49.20 + 1.35 = 50.55
At fifth stake	49.80 + .60 = 50.40
At sixth stake	50.40 + .15 = 50.55
At D	51.00 + .00 = 51.00

EXAMPLE FOR PRACTICE

Find the corrections in grade and the corrected elevations at stakes 100 feet apart if the vertical curve is 600 feet long. Grade of CV = − 1.6 per cent.; of VD = + .2 per cent.; elevation of V = 128.66 feet.

Ans. { Corrections in grade: .00, .15, .60, 1.35, .60, .15, and .00
Corrected elevations: 133.46, 132.01, 130.86, 130.01, 129.46, 129.21, and 129.26 }

---

100. Table for Vertical Curves.—Table II gives the corrections in grade, am, bm, etc., Figs. 27 and 28, for various gradients and lengths of vertical curves. The first column contains the total change in the rate of grade G at the angle V. If both grades are ascending [Fig. 26 (b)] or both grades descending [Fig. 25 (b)], the change in the rate of grade is evidently the difference of the two rates. If one grade is ascending and the other descending [Figs. 25 (a), 26 (a), 27, and 28], the change in the rate of grade is the sum of the two rates.

Opposite each value of G in the first column, there are given the corrections in grade at stakes 0, 50, 100, etc. feet from C. These corrections are also to be applied to the corresponding stakes distant 0, 50, 100, etc. feet from D. The table assumes that a 400-foot curve will be used where G is less than 1.1, a 600-foot curve where G lies between 1.0 and 1.9, and an 800-foot curve for higher values of G.

EXAMPLE.—To solve the examples of Arts. **98** and **99** by means of Table II.

SOLUTION.—In the example of Art. **98**, $G = .4 + .5 = .9$. In Table II, opposite the value .9 under G are found the corrections, .00, .03, .11, .25, and .45. The solution is now completed as before.

TABLE II

CORRECTIONS IN GRADE FOR VERTICAL CURVES

G	Whole Length of Vertical Curve	Distance From Beginning or End of Curve								
		0	50	100	150	200	250	300	350	400
.3	400 feet	0	.01	.04	.08	.15				
.4		0	.01	.05	.11	.20				
.5		0	.02	.06	.14	.25				
.6		0	.02	.08	.17	.30				
.7		0	.02	.09	.20	.35				
.8		0	.03	.10	.23	.40				
.9		0	.03	.11	.25	.45				
1.0		0	.03	.13	.28	.50				
1.1	600 feet	0	.02	.09	.21	.37	.57	.83		
1.2		0	.03	.10	.23	.40	.63	.90		
1.3		0	.03	.11	.24	.44	.67	.98		
1.4		0	.03	.12	.26	.47	.73	1.05		
1.5		0	.03	.13	.28	.50	.78	1.13		
1.6		0	.03	.13	.30	.53	.83	1.20		
1.7		0	.04	.14	.32	.57	.89	1.28		
1.8		0	.04	.15	.34	.60	.94	1.35		
1.9	800 feet	0	.03	.12	.27	.48	.74	1.07	1.46	1.90
2.0		0	.03	.13	.28	.50	.78	1.13	1.53	2.00
2.1		0	.03	.13	.30	.53	.82	1.18	1.61	2.10
2.2		0	.03	.14	.31	.55	.86	1.24	1.68	2.20
2.3		0	.04	.14	.32	.58	.90	1.29	1.76	2.30
2.4		0	.04	.15	.34	.60	.94	1.35	1.84	2.40
2.5		0	.04	.16	.35	.63	.97	1.41	1.91	2.50
2.6		0	.04	.16	.37	.65	1.02	1.46	1.99	2.60

In the example of Art. **99**, $G = 1.2 + .6 = 1.8$. In Table II, opposite the value 1.8 of G, are found the corrections, .00, .15, .60, and 1.35. The solution is completed as before.

EXAMPLE FOR PRACTICE

Solve the examples for practice in Arts. **98** and **99** by means of Table II.

---

101. Selection of Length for a Vertical Curve. Theoretically, the length of a vertical curve depends on the length of the longest train that is to pass over the curve, and also on the whole change of gradient G (Art. **100**). A simple theoretical formula is

$$\text{Length} = G \times \text{longest train}$$

Thus, if the length of the longest train is 800 feet, and the whole change of gradient is 1.9 per cent., the length of the vertical curve should be $800 \times 1.9 = 1{,}520$ feet. Practically, however, so long curves are not inserted. Many roads use the uniform length of 400 feet for all vertical curves. If any difference is made, the curves should be longer on a sag than on a spur, for the shock to the roadbed and rolling stock that arises from suddenly changing a rapid downward motion of a heavy train into an upward motion is very great. The length obtained from Table II will be found amply sufficient for any curve that is at a sag; at a spur, the curve may be taken 200 feet shorter than the table indicates, provided that the whole length is never reduced to less than 400 feet.

TRESTLES

INTRODUCTION

1. Definition.—A **wooden trestle**, as considered in railroad work, is a structure intended to carry one or more railroad tracks at an elevation of about 5 feet or more above the natural surface of the ground. Trestles are used as substitutes for earth embankments, either temporarily or permanently.

2. Extent of Trestling.—It was estimated in 1889 that there was in the United States about 2,400 miles of railroad trestle (single track) in a total railroad mileage of about 160,000 miles. At the present time (1907), the railroad mileage is considerably in excess of 200,000 miles. At the same rate (1.5 per cent.), this would mean that there is at present about 3,000 miles of railroad trestling. It is very probable that the percentage has been reduced, since trestles are often built merely as temporary structures, and the recent years of prosperity have enabled many railroads to replace much of their trestling with permanent earth embankments or with viaducts of metal or stone. In spite of all these substitutions, however, it is still true that there are nearly 3,000 miles of wooden trestling. These trestles involve a yearly cost for maintenance that averages one-eighth of the cost of construction. The amount of timber required for this maintenance and for new construction is so great that it engages the very serious attention of the Forestry Department of the United States Government. Therefore, any improvement in the design that will result in an economy of timber is of high financial value.

3. Classification of Trestles.—Trestles may be classified into permanent trestles and temporary trestles. They are further subclassified according to their construction and use. They are permanent when they cross a shallow but wide waterway, or where for any reason an embankment is not permissible. Temporary trestles are generally built when it is necessary to open the road for traffic very quickly, and also to replace a structure that has been destroyed by accident.

Wooden trestles may be divided, according to their methods of construction, into two general classes; namely, **pile trestles**, in which the bents consist of piles united by a cap, and **framed trestles**, in which the bents consist of squared timber members framed together.

A trestle **bent** is a combination of timbers that supports the floor system of the trestle, the bents being spaced at regular intervals—usually about 15 feet.

4. Comparative Cost of Trestles and Embankments.—The height at which it becomes more economical to use trestling than embankment varies widely, depending on the locality, the cost of timber and labor, and the character of material available for making the fill. There are, of course, many situations, such as deep swamps or waterways, where an embankment is not practicable. The only question then is to choose between a wooden and an iron structure.

Table I shows the approximate relative cost of embankment and trestle in sections of 100 feet, excluding rails, ties, and ballast on the former, and rails, guard-rails, and ties on the latter. As will be observed, the cost of an embankment increases in a vastly greater ratio than its height; while, on the other hand, the cost of trestling does not increase nearly so rapidly as the height, especially for heights under 50 feet. In comparing the cost of a trestle with that of an embankment, it must be remembered that a culvert will be required under the latter, and its cost must be considered.

TABLE I

APPROXIMATE RELATIVE COST (IN DOLLARS) OF EMBANKMENTS AND TRESTLES

Height From Surface of Ground to Grade (Subgrade) Feet	Cost of Embankment 100 Feet Long; Roadbed 14 Feet Wide; Slope $1\frac{1}{2}$ to 1					Cost of Trestle 100 Feet Long					
						Pile Trestle Having an Average Penetration of 10 Feet; Cost of Piling, in Place, 35 Cents per Lineal Foot			Framed Trestle		
	Width of Embankment at Base Feet	Cost per Cubic Yard, in Cents				Cost of Timber (Including Iron) per M., B. M.*					
		16	18	20	22	$30	$35	$40	$30	$35	$40
5	29	64	72	80	88	376	407	439	283	330	378
10	44	113	127	141	155	441	476	512	385	449	514
15	59	325	366	406	447	508	544	580	464	541	618
20	74	521	587	652	718	576	613	651	541	631	721
25	89	764	859	955	1,050	748	803	858	796	928	1,060
30	104	1,049	1,180	1,312	1,443	816	872	928	872	1,017	1,163
35	119	1,380	1,552	1,725	1,897	990	1,065	1,140	1,058	1,234	1,410
40	134	1,754	1,974	2,193	2,412	1,057	1,132	1,218	1,133	1,322	1,510
45	149	2,174	2,446	2,717	2,989				1,202	1,404	1,606

*The expression *per M., B. M.* means *per thousand feet, board measure.*

Table II gives the cost of pile and framed trestles complete, including floor systems, for heights from 5 to 45 feet, inclusive, in sections of 100 feet.

TABLE II

COST (IN DOLLARS) OF PILE AND FRAMED TRESTLES

Height Feet	Pile			Framed		
	$30	$35	$40	$30	$35	$40
5	546	605	665	453	528	604
10	611	674	738	555	647	740
15	678	742	806	634	739	844
20	746	811	877	711	829	947
25	918	1,001	1,084	966	1,126	1,286
30	986	1,070	1,154	1,042	1,215	1,389
35	1,160	1,263	1,366	1,228	1,432	1,636
40	1,227	1,332	1,444	1,303	1,520	1,736
45				1,372	1,602	1,832

The cost of timber work complete and the cost of earthwork are so variable that even Tables I and II do not have a sufficient range to cover all cases; but the figures given are valuable as a general guide in making comparative and preliminary estimates.

When using Table I, it must not be forgotten that the cost of the culvert under the embankment depends on its size and type of construction; the length of the culvert is of course somewhat less than the width of the embankment at its base. Adding the cost of the culvert to that of the embankment will lower the height at which the embankment becomes more expensive than the trestle.

5. Technical Terms.—The various technical terms used in trestle work will now be defined and illustrated. The diagrams given throughout this Section should be studied for further and perhaps clearer illustrations of the various parts of a trestle.

Bents are of two kinds; namely, framed bents and pile bents. A **framed bent** (*1*, Fig. 1; also shown in Figs. 69 and 70) is a frame of timbers that rests on an independent

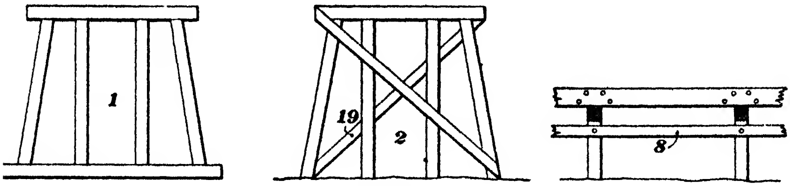


Fig. 1

foundation and supports the floor system. A **pile bent** (*2*, Fig. 1; also shown in Fig. 71), is a support for a trestle floor system; this bent consists essentially of piles driven ver-

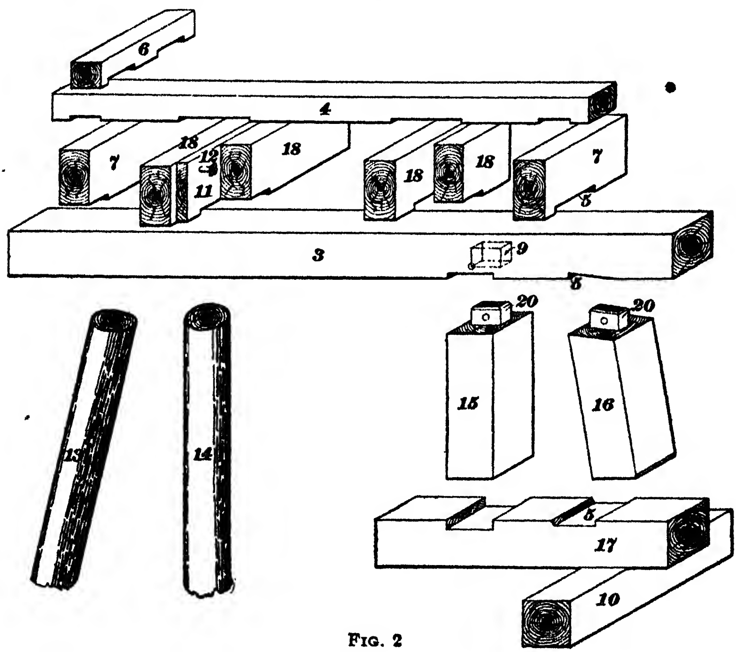


Fig. 2

tically, or nearly so, the piles being topped with a cap and, if necessary, stiffened with cross-bracing.

The **cap** (*3*, Fig. 2) is the cross-timber at the top of the posts.

The cross-tie (*4*, Fig. 2) is the special form of tie used for trestles.

Dapping (*5*, Fig. 2) is the name given to a groove cut in a timber member for rendering it more secure against slipping out of place. **Gaining** or **notching** is used in the same sense as the term *dapping*.

A **guard-rail** (*6*, Fig. 2) is a timber laid on the ties and perpendicular to them, for the double purpose of keeping the ties in place and of preventing a derailed car wheel from rolling off the trestle floor.

A **jack-stringer** (*7*, Fig. 2) is a stringer placed immediately under the guard-rail.

A **longitudinal brace** (*8*, Fig. 1) is a timber brace that runs longitudinally with the length of the trestle and braces adjacent trestle bents.

A **mortise** (*9*, Fig. 2) is a hollow cut into a timber to receive the tenon on the end of a post.

A **mud-sill** (*10*, Fig. 2) is one of a series of timbers sometimes used as the foundation for a framed trestle, the timbers being laid perpendicular to the sill of the trestle bent.

A **packing-block** (*11*, Fig. 2) is a strip of timber—usually about 2 inches thick, 12 inches wide, and 5 or 6 feet long—laid between parallel stringers and bolted to them.

Packing-bolts (*12*, Fig. 2) are the bolts that fasten the stringers and packing-blocks into a compact structure.

Piles.—Piles that do not run vertically are said to be **battered, inclined,** or **braced** (*13*, Fig. 2). If used at all, they are placed at the ends of pile bents. **Vertical, plumb,** or **upright** piles (*14*, Fig. 2) are piles driven vertically.

Posts.—The posts of a framed trestle bent that are not vertical are said to be **battered** or **inclined** (*16*, Fig. 2). When used, they are placed at the ends of the trestle bent. **Vertical, plumb,** or **upright** posts (*15*, Fig. 2) are the vertical posts of a framed trestle bent.

The **sill** (*17*, Fig. 2) is the cross-timber on which the posts of a framed trestle bent rest, corresponding with the cap at the top.

A **stringer** (*18*, Fig. 2) is one of several timbers connecting adjacent trestle bents and forming the main supporting timbers of the floor system.

A **sway-brace** (*19*, Fig. 1) is a comparatively light timber used on each side of a framed or pile trestle bent to stiffen the bent against lateral distortion.

A **tenon** (*20*, Fig. 2) is the projection on the end of a post which fits into the mortise.

A **treenail** is a wooden nail, usually made of hard wood, driven through the mortise and tenon [see Fig. 8 (*b*)].

Waling Strip.—See longitudinal brace *8*, Fig. 1.

BENTS

PILE BENTS

6. General Considerations.—Where the height of a trestle bent does not exceed 30 feet, and where the ground is soft and marshy, so that a suitable foundation is difficult to obtain, pile trestle bents are frequently used, since they are constructed rapidly, and the driving of the piles serves the double purpose of constructing the bent and also its foundation. The main disadvantage of pile bents is that the piles, being subject to alternations of wetness and dryness near the surface of the ground, decay rapidly. When pile bents are used for greater heights than 30 feet, only a comparatively small part of the piles penetrates the ground, and though they may reach a substantial bottom, the bent is weak, owing to the small diameter of the pile and the small proportion of heart timber at the top of the tree. It is the heart timber alone that can long resist decay, and at the surface of the ground, where the timber is alternately wet and dry, decay sets in as soon as the structure is erected, and in a few years, at best, the piles must be renewed, though the remainder of the trestle may be in a comparatively sound condition.

7. Piles.—The subject of piles, pile driving, and pile foundations is fully treated in *Foundations*, Part 2, so that here it will be sufficient to consider only that part of the subject which is peculiar to trestle work. Piles should be cut from live, straight, thrifty trees, free from dead or loose knots, wind shakes, and all signs of decay. They should have a butt diameter of from 12 to 15 inches, and a top diameter of from 7 to 10 inches inside the bark. *Squared piles*, which are used in a limited way, should measure 12 inches square at the butt and not show more than 2 inches of sap wood on the corners. It is the custom on some railroads to paint the pile for a short distance above and below the ground line with hot tar, in order to retard decay.

Timber suitable for piles may be found in most sections of the United States. The different varieties of timber commonly used for piling are named in the following list in the order of their suitability:

red cedar	white pine	white oak
black cypress	redwood	post oak
pitch pine	elm	tamarack
yellow pine (long-leaf)	spruce	hemlock

8. Construction of Pile Bents.—The spacing of the piles forming the bent varies considerably, with different constructors, though the general arrangement is the same.

For a height of bent not exceeding 5 feet, and where the railroad is to carry only a moderate traffic, a three-pile bent is generally adopted, one pile being placed directly on the center line and the others spaced from 3 feet 6 inches to 5 feet out, the piles being driven vertically (see Fig. 3). For trunk lines, however, whatever the height, all bents should contain at least four piles.

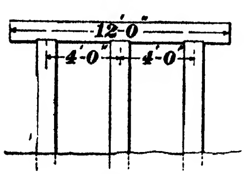


Fig. 3

For heights of from 5 to 15 feet, each bent should contain four piles driven vertically. The inner piles may be spaced from 4 to 5 feet, and the outer ones about 11 feet from center to center (see Fig. 4). Pile bents of this height

do not strictly require sway-bracing, provided that the penetration amounts to 6 or 8 feet in firm earth; it is the best

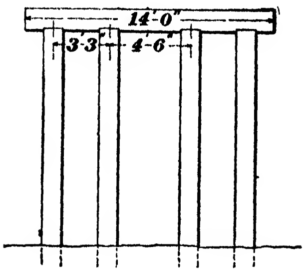


Fig. 4

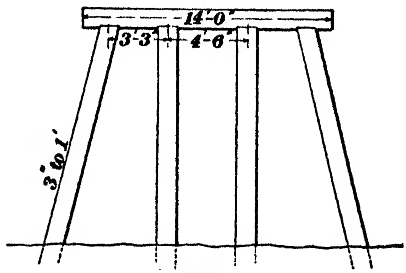


Fig. 5

practice, however, to provide sway-bracing on all bents. For heights exceeding 15 feet, it is well to batter the outside piles, as shown in Fig. 5. By this means, the width of the base and therefore the stability of the structure is considerably increased. Piles are battered from 2 to 4 inches to the foot, 3 inches being commonly adopted. Where the diameter of the pile at the cut-off point exceeds the width of the cap, the part of the pile that projects should be adzed off at an angle of 45°, as shown in Fig. 6.

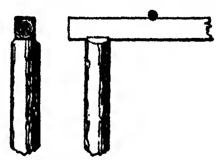


Fig. 6

9. Capping and Cutting Off.—When a floating pile driver is used, the sawing off and capping of the piles may follow the driving, at the convenience of the contractor, though it is better to follow the driving closely with the

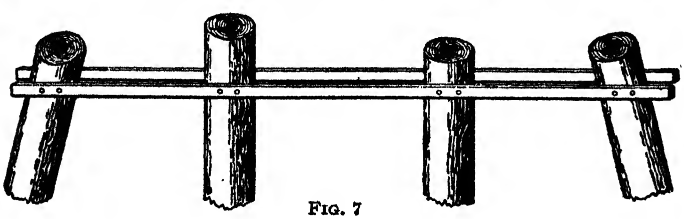


Fig. 7

caps and stringers. When a pile driver mounted on a car is used, each bent must be cut off and capped and the timbers laid before the driver can advance to the next bent.

As soon as a bent of piles is ready for cutting off, the height of the top of pile is given and a narrow, straight-edged strip of board (ordinary roofing lath serves well) is nailed on each side of the bent with its top edge at the proper height for cutting off (see Fig. 7). The cutting off is best done with a cross-cut saw worked by two men. If the piles are tenoned to the caps, the cutting necessary to form the tenon is done with the cross-cut saw.

10. Caps may be fastened to the piles in three ways; namely, by mortise and tenon, by drift bolts, or by dowels. For solid caps, a tenon 3 inches thick, 8 inches wide, and 5 inches long is a good size [see Fig. 8 (*a*)]. The top edges of the tenon should be chamfered and the mortise and tenon made so as to fit snugly. The parts are held together by means of treenails. Treenails are from 1 inch to $1\frac{1}{2}$ inches in diameter, and slightly tapering [see Fig. 8 (*b*)]. They should be made of hard wood, oak or locust being preferable. The hole made in the cap to receive the pin should be spaced a little farther from the base of the cap than the hole in the tenon from the tenon shoulder, so that, in driving the pin, the parts will be drawn together. Iron bolts or pins should never be used in place of wooden pins. Instead of crowding or drawing the parts together, the iron punches or cuts away any wood that lies in its path, merely increasing the size of the hole.

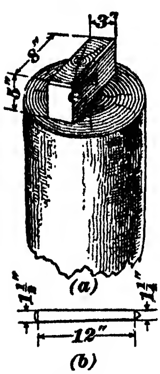


FIG. 8

11. When drift bolts or dowels are used, the piles are cut off level, and holes are bored in both cap and pile to receive the drift bolt or dowel. Sometimes two drift bolts or dowels are used at each pile, but commonly only one, which is sufficient. A hole is first bored through the cap into the pile head to receive the drift bolt, which should be somewhat larger than the hole, so that, in driving it, every cavity in the hole may be completely filled (see Fig. 9).

12. Dowels are of shorter length than drift bolts and extend only about half way through the caps (see Fig. 10). To drive dowels, they are first driven for about half their length into holes that have been bored in the tops of the piles to the proper depth. These holes should be exactly in line. Then, a series of holes are bored in the cap exactly in line and at corresponding distances apart. The cap is then placed over the dowels so that each dowel will enter its hole. The tops of the piles may be forced over to allow for a slight error of boring. The cap is then hammered down into place.

Another method of fastening caps to piles, and one that is rapidly growing in favor, is by means of split caps, shown in Fig. 11, in which the cap, instead of being a single piece of timber, consists of two pieces, each half the size of the

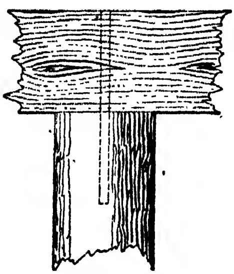


FIG. 9

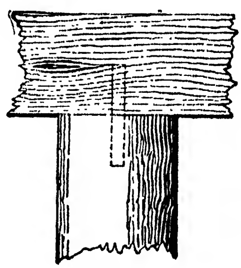


FIG. 10

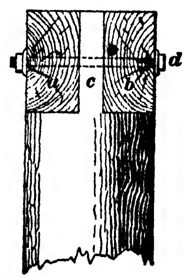


FIG. 11

single piece. For example, instead of using for the cap a single stick of timber, 12 in. × 12 in., as shown in Figs. 9 and 10, two pieces *a* and *b*, Fig. 11, each 6 in. × 12 in., are substituted. A tenon *c*, 3 inches wide and extending the full width of the pile, is formed at its top, and a cap is placed on each shoulder against the tenon. A $\frac{3}{4}$-inch bolt *d* is passed through the caps and tenon, and holds them firmly in place. The caps should not be notched, and the piles should be sawed off smooth and level so as to afford a good bearing for the caps.

Some of the advantages claimed for split caps are the following:

1. On account of the smaller size, better timber can be obtained at less cost.

2. Repairs can be made with ease and great economy of time and labor.

3. Traffic need not be interrupted nor endangered while repairs are being made.

4. The caps may be replaced without cutting or injuring any other part of the structure.

5. There is some economy in material, because, unless both sticks are decayed, it is not necessary to replace the whole cap, but only that part which is no longer in a serviceable condition.

FRAMED BENTS

FOUNDATIONS

13. Framed bents are composed entirely of sawed timber, and are placed on a foundation, the objects of which are to insure stability to the structure and, by raising it from the ground, to prolong its life. All timber placed in direct contact with the ground partakes of all its changing conditions of drouth and moisture, which soon induce decay. Among the various kinds of foundations used for trestle bents are the following: *masonry*, *pile*, *sub-sill*, *grillage*, *crib*, *solid rock*, and *loose rock*.

14. Masonry foundations are the best. They are ordinarily composed of rubble masonry laid in cement mortar. Good forms of masonry foundations are shown in

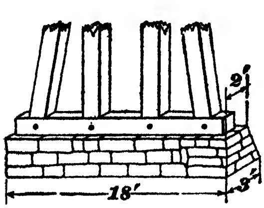


Fig. 12

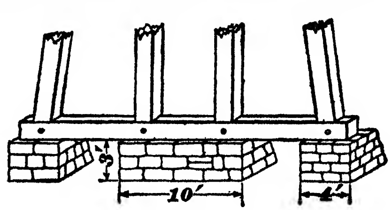


Fig. 13

Figs. 12 and 13. In northern latitudes, trenches at least 2 feet in depth should be excavated for these foundations to prevent them from being heaved by hard freezing. In

exposed localities where the freezing is very severe, it may be necessary to excavate the foundation trenches to a depth of 3 feet.

It is bad practice to use irregularly shaped stone, especially cobblestone, in building trestle foundations. The continual jar caused by passing trains is likely to injure seriously masonry of an inferior quality. Dry rubble, if built of long stones with horizontal beds, and well bonded, is far superior to mortar rubble of poor quality. The foundation walls shown in Figs. 12 and 13 are supposed to be laid in foundation pits 2 feet deep, and to extend 1 foot above the surface of the ground. The ends of the wall should be vertical, and the sides battered about 2 inches to the foot.

15. Pile Foundations.—When pile foundations are employed for marshy ground that is not too deep, it is a good plan to allow the piles to extend far enough above the surface of the ground to form a bent, which is capped and a framed bent placed on top of it. Where the trestle crosses a waterway, it is good practice to place a framed bent on a pile foundation of such height as to remain always under water. The decay due to alternate wetting and drying is thus confined to the framed portion, which can easily be renewed.

16. Sub-sills or mud-sills are blocks of timber placed under the main sills to raise them above the ground to prevent decay and to distribute the pressure over a greater area.

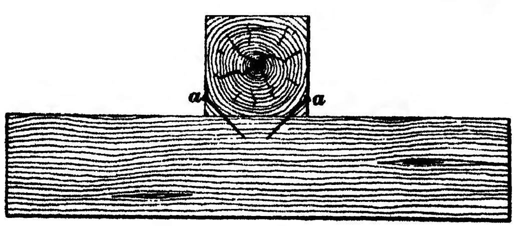


FIG. 14

Some recommend plank 3 or 4 inches thick, but 12″ × 12″ timber is far better, and the additional cost is trifling compared with the solidity of foundation and security against

decay. The sills and sub-sills should be fastened together, to prevent the latter from being displaced. As the strain is slight, 6-inch cut spikes, driven as shown at *a*, *a*, Fig. 14, will serve for a fastening.

17. Grillage.—Grillage is defined, and the general method of construction illustrated, in *Foundations*, Part 2. It is used as the foundation for trestles when the soil is so soft that a large area for the foundation is necessary. Placing the timbers at a distance apart of two or three diameters has virtually the same effect as a continuous foundation

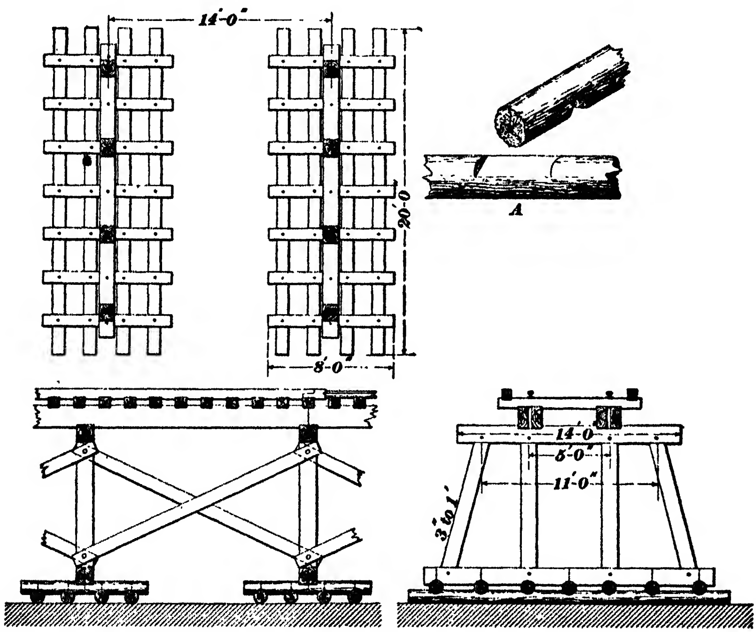


Fig. 15

with the same gross area, but the economy of material is very great. Generally, the grillage timbers are round trunks of trees; such timber serves its purpose well and is, perhaps, more durable than solid timber, besides being cheaper. The timbers are usually notched at each intersection, as shown in detail at *A*, Fig. 15, and should be drift-bolted at the

intersections. The tops of the cross-logs are adzed to a common level to receive the sills of the trestle bents, which are drift-bolted to the grillage. The grillage shown in Fig. 15 was employed in the Northern Adirondacks in crossing a subterranean lake. The lake was covered with earth to the depth of several feet and overgrown with brush and timber, but was unsafe for an embankment. The longest piles failed to reach bottom. By means of this grillage, the weight of the trestle and train load was distributed over such an area that it could be safely carried. Although the road has been in operation for many years, no considerable settlement has taken place.

18. Cribs.—A **crib** is a framework of timber designed to be weighted down by means of a filling of stone or earth. Ordinarily, cribs are made somewhat in skeleton form; that is, so that the timbers are spaced several inches apart. This economizes timber, and does not interfere with the necessary strength. Crib foundations have the advantage of

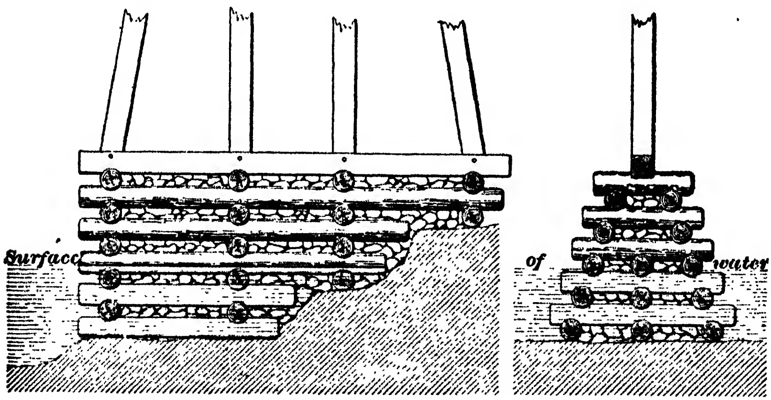


Fig. 16

cheapness and rapidity of construction, but lack durability. If a trestle crosses a stream and it is necessary to place one of the trestle bents in the stream, such a foundation can be readily constructed and used. It is sometimes necessary to locate a line on the very edge of a stream where an embankment would probably be washed away: in such cases, a crib

construction is of great value, since it is so readily constructed and will not be washed away by a swift current. An illustration of such a foundation is shown in Fig. 16. It will be observed that the bottom of the crib can be so made as to adapt it to an irregular or uneven bottom.

19. Pile Bents on Solid Rock.—If the surface is solid rock, all that is necessary in preparing a foundation is to smooth off a place for each post to stand on. The readiest way to fasten each post is by means of a dowel, which should reach 5 or 6 inches into the rock and an equal distance into the post. In some instances, holes are blasted into the surface rock and the posts stood in the holes. After the posts are fastened together to form a bent, the vacant space about the foot of each post is filled with rich cement mortar. When such foundations are used, the system of bracing should be ample, especially where the trestle is built on a side hill, which requires posts of much greater length on the lower than on the upper side.

20. Loose Rock.—Where masonry would prove too costly, satisfactory foundations may be constructed of loose rock. Foundations of this character are made by first

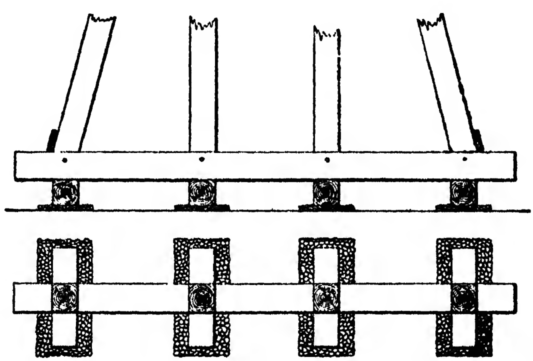


FIG. 17

excavating a short trench directly under each post, as shown in Fig. 17, and then filling the trenches with broken stone, on which sub-sills are placed to form the supports for the sills. If water accumulates in the trenches, it may

be drained off by digging around the foundations shallow open ditches and leading them away to lower ground. This will at least save the sub-sills from contact with water and so preserve them from rapid decay.

21. Drip Holes.—The tendency of water to accumulate in mortises hastens decay of the timbers. To prevent this, every mortise forming a receptacle for water should be provided with a drip hole ½ inch in diameter bored with a downward inclination from the bottom of the mortise to the outside of the timber. Two methods of boring drip holes are shown in Figs. 18 and 19. In Fig. 18, the drip hole *a* leads vertically downwards from the mortise; in Fig. 19, the hole *b* is inclined downwards to the side of the sill.

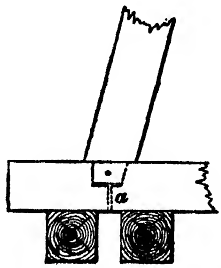


FIG. 18

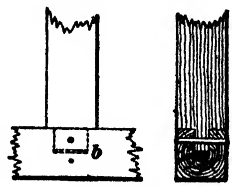


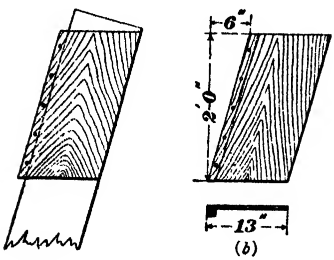
FIG. 19

DETAILS OF CONSTRUCTION

22. Posts.—There are usually four posts to a bent: two vertical, or plumb, posts; and two inclined, or batter, posts. The standard dimensions of trestle posts are 12 in. × 12 in., though other dimensions are sometimes used. The plumb-posts should be spaced from 4 to 5 feet between centers, and the batter posts 11 feet from center to center at the top. The inclined posts should have a batter of 3 inches to the foot. This gives a broad base, adding considerably to the stiffness and stability of the structure. It is poor economy to stint the dimensions.

23. Framing Batter Posts.—It is very important that the upper and lower ends of the batter posts should be cut off at precisely the proper angle, so that when they are placed in position the surfaces may fit the cap and sill. When a large number of posts must be framed with the

same batter, the simplest plan is to make a **templet.** Such a templet is illustrated in Fig. 20 (*b*), the batter being 1 horizontal to 4 vertical. A piece of ½-inch hardwood board is cut to the proper inclination (in this case 1 : 4, or 6 inches to 2 feet), and a 1-inch cleat is fastened to the edge of the board. A piece of timber a little longer than the distance between the extreme corners at each end may then be cut to the exact length by placing the templet on the post, as illustrated in Fig. 20 (*a*). In this case, the templet becomes merely a modified form of T square, the cleat corresponding to the head of the square. The upper and the lower edge should be exactly parallel. The upper and the lower end of the post may be marked by simply sliding the templet along one edge of the post, the upper edge serving for the top cut and the lower edge for the lower cut.



(*a*) Fig. 20 (*b*)

One method of framing the posts to the cap is illustrated in Fig. 21. The method has the doubtful advantage of economy, since each batter post and its corresponding vertical post are framed into one large mortise instead of into separate mortises. Another method of construction is that illustrated in Fig. 22, in which all the posts are battered. In this case, the outer posts have a uniform batter, and therefore the length of the sill varies directly as the height of the trestle. The inner posts change their batter with each change of height. It is very questionable whether the variation for

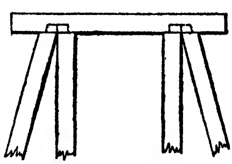


Fig. 21

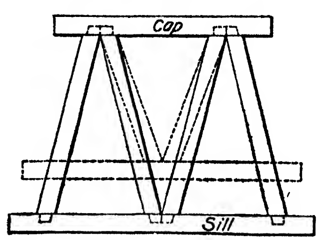


Fig. 22

each height does not produce more labor and liability to error in the framing than would result from adopting a batter such as the inner posts would need for the highest trestle to be constructed, and then using this batter uniformly for all inner posts. This would separate the bases of the inner posts for the lower trestles.

24. Caps.—If solid, caps should be of not more than 12″ × 12″ timber; while, in a majority of cases, 10″ × 10″ stuff would serve equally well, frequently assuring better material as well as effecting a considerable economy. There are several ways of joining the sills, posts, and caps together, but only three are in general use; namely, by mortise and tenon, by drift bolts, and by dowels. These have already been described.

A tenon (see *20*, Fig. 2) 3 inches thick, 8 inches wide, and 5 inches long is a good size. The mortise should be about ½ inch deeper than the length of the tenon, and well finished, so that the tenon will fit snugly. In boring the hole for the treenail, the same precaution should be taken with framed bents as with pile bents (see Art. **10**). All mortises so placed as to hold water should be provided with drip holes.

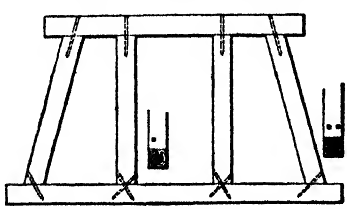


FIG. 23

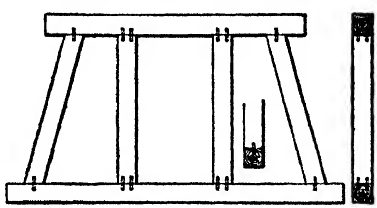


FIG. 24

The use of drift bolts in connecting cap and sill with post is shown in Fig. 23, and the manner of making dowel connections in Fig. 24.

Two drift bolts are required to fasten a post to the sill, and one in securing it to the cap. A hole must be bored for each drift bolt. The drift bolts used for these connections are either of square or of round iron. If square, ¾-inch iron will answer, or iron of equivalent weight, if round. Dowels are usually of ¾-inch round iron.

On some roads, split caps and sills are preferred; when such is the case, the connections with the post are made similar to split-cap connections of pile trestles (see Fig. 11).

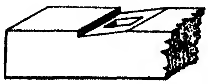


FIG. 25

FIG. 26

It is customary to notch both cap and sill at the post joints. For the battered posts, both beveled and square notches are employed (see Figs. 25 and 26), though the former (Fig. 25) are to be preferred.

25. Distance Between Bents.—Bents should be uniformly spaced, the distance between centers of bents being from 12 to 16 feet, depending on the character and cost of timber. Spans from 12 to 14 feet are most common.

FLOOR SYSTEM AND BRACING

FLOOR SYSTEM

26. Corbels.—A **corbel** is a piece of timber from 8 to 12 inches wide, 10 to 12 inches thick, and about 6 feet long. It is placed under and parallel with the stringers. Its object is to relieve the ends of the stringers from the crushing effect due to the weight of the stringers and their load. When

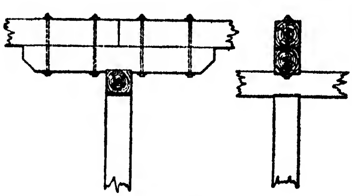


FIG. 27

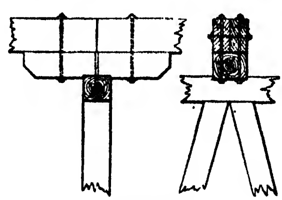


FIG. 28

stringers are made of a soft wood, they are likely to be crushed at the ends where they rest on the caps. A corbel will increase this area five or six times, and thus prevent the stringer from being crushed. Incidentally, the vertical bolts that fasten the corbels to the stringers, as shown in

Figs. 27 and 28, tie the stringers to the corbel, and so bind the stringers together. The corbel is always made of hard wood, as white oak, which can resist crushing more readily than the softer wood that may be used for the stringer. Notwithstanding these advantages, some of the best engineers object to the use of corbels. They certainly make the structure more complicated; and in cases where the stringers can be made of hard wood, corbels are scarcely necessary or advantageous. The corbel should be notched down on to the cap. One effect of the corbel is virtually to shorten the span of the stringers, thereby increasing the strength of the structure.

27. Stringers.—The term **stringer** has already been defined and illustrated in Art. 5 (see also Figs. 39 to 42). One stringer or group of stringers is always placed under each rail. Generally, two or more timbers are used, rather than one timber of the requisite cross-section. This is done because it is not always practicable to obtain timbers of large cross-section in a perfectly sound condition; because this method is far less expensive; because the smaller timbers are more easily handled; and because, if one of them decays or is damaged by accident, the other stringers are not necessarily affected. The stringers should be separated by packing-blocks, as will be presently explained.

Wherever practicable, the stringers should be long enough to cover two spans. Then they are made to overlap so that over each cap there is at least one joint and one continuous stringer (see Figs. 39 to 42). In order to secure the stringers to the cap, they are sometimes notched on the under side; this prevents any longitudinal motion. If corbels are used, the corbels are notched on the cap and the stringers are bolted to the corbels. To prevent lateral motion, **spreaders** are placed on top of the cap between the stringers. These spreaders are pieces of heavy plank, usually about 3 inches thick, that are spiked to the top of the cap, as shown at *a*, Fig. 29. To prevent the possibility of the floor system being jarred loose from the caps, the stringers are

sometimes bolted to the caps with either screw bolts or drift bolts. The use of drift bolts in this way is very objectionable, as it is practically impossible to withdraw a drift bolt without splitting open the stringer; besides, it is unnecessary, since, if the stringer is secured against longitudinal and lateral motion as described, the weight of the floor system is amply sufficient to prevent any upward motion. The stringers are also stiffened by the ties, which are usually notched on their under side where they rest on stringers. This detail is also shown in Fig. 29.

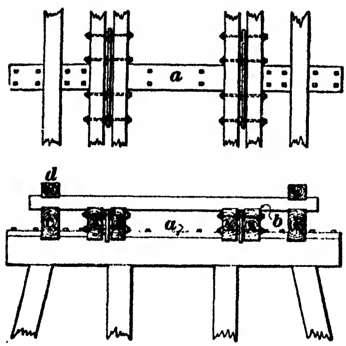


FIG. 29

28. Packing-Blocks and Separators.—If two pieces of sawed timber are placed side by side as close as possible, the joint between them will be wide enough to admit water readily, but not wide enough to allow the timber to dry quickly, the result being that the timber will decay in a short time. On this account, it is necessary to separate the stringers by a space of ½ inch or more. This is sometimes done by

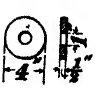


FIG. 30

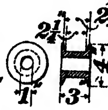


FIG. 31

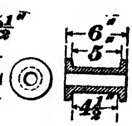


FIG. 32

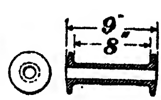


FIG. 33

FIG. 34

FIG. 35

using cast-iron washers or **separators**, which are essentially rings or spools of cast iron having a hole a little larger than the bolts used to fasten the stringers together, and of a length (parallel to the bolt) that varies between ½ inch and 9 inches. Several forms of cast-iron separators are shown in Figs. 30 to 35.

A **packing-block** is another kind of separator. It is a plank about 2 inches wide and from 4 to 6 feet long.

Packing-blocks are illustrated in Figs. 36 to 38, and, also, in connection with the stringers, in Figs. 39 to 42, which show some of the best of the many styles of stringer joints. As

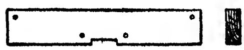


FIG. 36

FIG. 37

FIG. 38

shown, in the figures, the packing-blocks serve the additional purpose of scarfs to join the stringers together. Although they are sometimes packed in closely between the stringers, as shown in Fig. 39, it is usual to employ small cast-iron

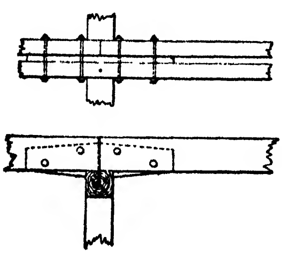


FIG. 39

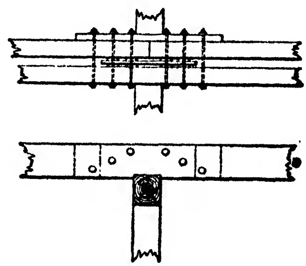


FIG. 40

separators even between the stringers and packing-blocks, for the same purpose as just given; namely, to prevent decay between the packing-blocks and the stringers.

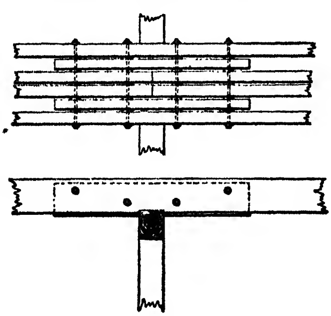


FIG. 41

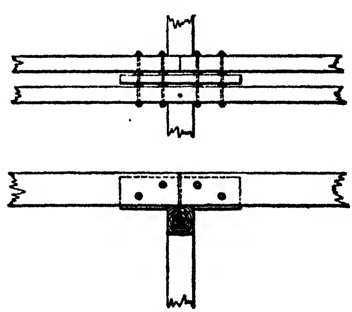


FIG. 42

29. Size of Stringers.—The size of stringers depends on the length of the span and the loads that the trestle must carry. When a trestle is very high, it is economical to

lengthen the span between trestle bents so as to reduce their number. On the other hand, a limit of span is very soon reached where stringers acting as beams cannot carry modern train loads. A span of 16 or 18 feet is about the limit, unless special means are used to truss the stringers, in which case the span may be increased to about 25 feet. This plan has the objection that all the stringers must break joints at every trestle bent, or else the stringers must have a length of 50 feet. It is very difficult to obtain stringer timber of the proper cross-section and 50 feet long. Yellow pine is the most commonly used timber for stringers, although white pine, spruce, and oak are used, if they can be obtained readily.

A jack-stringer composed of a single piece of timber, as shown at *c*, Fig. 29, is often placed near the ends of the ties and directly beneath the guard-rail, for the purpose of affording additional support to the ties in case of derailment. Without this support, the ties are likely to be broken by a derailed engine, and a total wreck follow; while, with it, provided that the guard-rail holds, the engine and train are likely to remain on the trestle. The jack-stringers should reach over two spans, and be bolted to the caps.

30. Ties.—Trestle ties vary in both section and length. A 7″ × 8″ × 12′ tie is considered a good size; the length provides for a jack-stringer. Many ties are only 9 feet in length, while others are 10 feet. They are spaced from 12 to 24 inches between centers, although 15 inches should be the limit. The reason for placing them close together is that, in case of derailment, ties closely spaced afford a fairly continuous support for the car wheels, especially the driving wheels, while those widely spaced allow the wheels to drop between and tear up the ties, with the result that a wreck is likely to follow. On some roads, none of the ties are fastened to the stringers; on others, every fifth, or even every other tie is fastened,

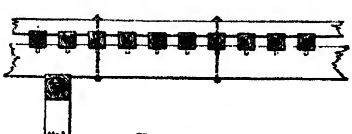


FIG. 43

spikes or lagscrews being generally used for the purpose. Dowels are used for tie-fastenings, but only to a limited extent (see Fig. 43).

Four standard floor systems are given in Figs. 44 to 47, showing the arrangement and mode of fastening cross-ties.

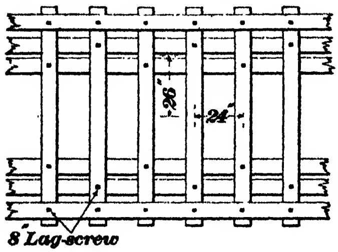


FIG. 44

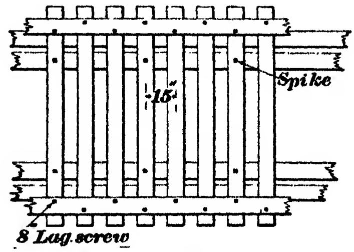


FIG. 45

In the Pennsylvania standard, Fig. 44, the wide spaces between the ties are a serious objection, as in case of derailment they render wreck almost certain. The dimensions and arrangement of ties in Fig. 45 are especially recom-

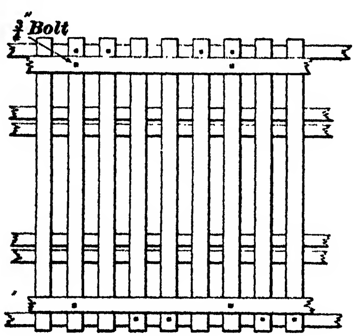


FIG. 46

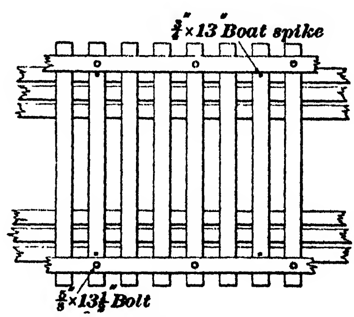


FIG. 47

mended. Ties should always be notched down 1 inch over the stringers. Notching prevents any lateral movement and strengthens the floor system.

31. Guard-Rails.—Guard-rails are an important part of the trestle: they serve the purposes of preventing a train from leaving the trestle in case of derailment, of maintaining the spacing of the ties, and of adding weight and

strength to the floor system. Where a jack-stringer is used, the guard-rail is placed directly above it. Guard-rails should be notched down on the ties, usually 1 inch, and fastened to them with either bolts or lagscrews, and should have a section not less than 6 in. × 8 in. The length depends on the available supply, but no length under 16 feet should be used. Commonly, the guard-rails and cross-ties are of the same-sized timber, 7 in. × 8 in. being a standard size, the lengths running from 20 to 24 feet.

Guard-rails are spliced in a variety of ways. Various forms of splices are shown in Figs. 48 to 51. The halved joint, Fig. 48, is recommended as simple and effective. Joints should come directly over a tie and be broken; that is, a joint on one guard-rail should be on line with the middle point of the opposite guard-rail. Each joint should be fastened with either a bolt or a lagscrew. Bolts are much to be preferred to lagscrews for fastening guard-rails to ties.

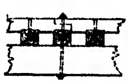


FIG. 48

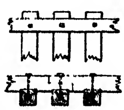


FIG. 49

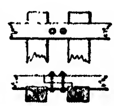


FIG. 50


FIG. 51

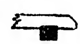


FIG. 52


FIG. 53

Lagscrews tear the fiber of the wood, and form cavities that hold moisture and induce decay. The best plan is to bolt every fourth or fifth tie to the guard-rail, and spike the remaining ties with 10-inch boat spikes. A punched washer should be put under the head of each lagscrew. It is a waste of time and an injury to the timber to countersink the heads of bolts or lagscrews. The holes form receptacles for water, which soon induces decay. A 3- to $3\frac{1}{2}$-inch cast washer should be placed under the head and nut of each bolt, the nut being placed up so as to make inspection and repairs easy.

32. The ends of the guard-rail should be beveled, as shown in Figs. 52 and 53. The guard-rails should extend from 20 to 30 feet from the trestle on to the embankment. They should be flared outwards so that at their extremities

they will be from 3 to 4 feet from the rails (see Fig. 54). The object of flaring them is to assist in passing the trestle in safety any car that may have been derailed on the embankment. On some roads, in addition to these flaring guards,

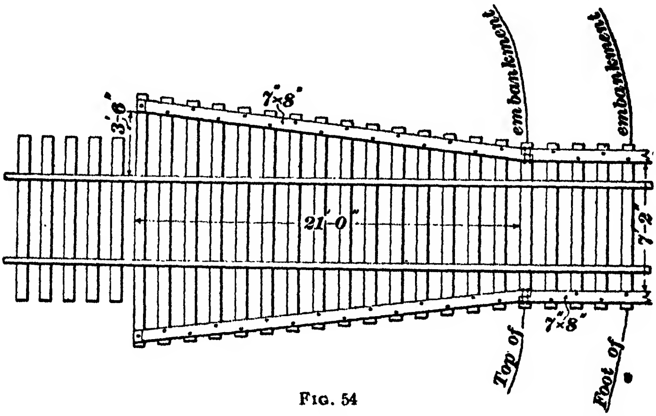


FIG. 54

bumping posts are placed near the end of the embankment, but their value is not generally admitted.

An additional safeguard, which is in general use on some lines, is an inner guard-rail of the same section as the main rail, placed $2\frac{1}{2}$ inches inside the rail. Objection is made by some to this form of guard-rail on the ground that it forms a lodgment for detached pieces of the truck, such as brake shoes, box lids, etc., causing the wheels to mount the rails. The tendency of wheels to mount the wooden guards may be prevented by fastening a strip of angle iron on the upper inside edge of the guard-rail.

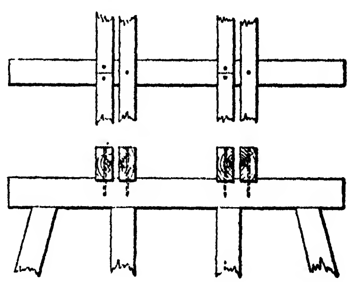


FIG. 55

33. Fastening Down the Floor System.—There are several methods of fastening down the floor system to the bents, some of which have already been mentioned. The method generally adopted is to drift-bolt the stringers to

the caps (see Fig. 55). The only objection to this method has already been stated; namely, the difficulty of removing the bolts when making repairs. This mode of fastening the floor system has the merits of simplicity and security, and is more used than any other. Another method is to bolt the stringers to the caps, in which case the posts must be so spaced as to allow the bolt to pass through the cap. On some roads the stringers are not fastened to the caps, the weight of the floor system being depended on to hold them down.

BRACING

34. Sway-Bracing.—**Sway-bracing**, defined and illustrated in Art. **5**, and further illustrated in Figs. 56 and 57, is used to resist any lateral force, such as wind pressure, that would tend to make the trestle collapse laterally. Pile or framed bents under 10 feet in height seldom require any sway-bracing. Bents from 10 to 20 feet in height require a single **X** brace of 3″ × 10″ plank extending diagonally from the upper corner of the cap to the foot of the opposite pile, or to the outside corner of the sill, in the case of a framed bent (see Fig. 56). For bents from 20 to 40 feet in height, two **X** braces separated by 3″ × 10″ horizontal planks spiked to both sides of the bent, as shown in Fig. 57, afford ample bracing. There are two methods of fastening the sway-braces, both of which are in general use. In one, the sway-braces are fastened to the piles or posts with ¾-inch bolts and cast washers, as shown in Fig. 56; in the

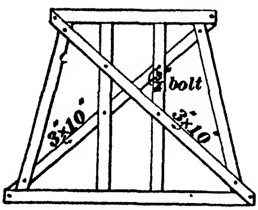


FIG. 56

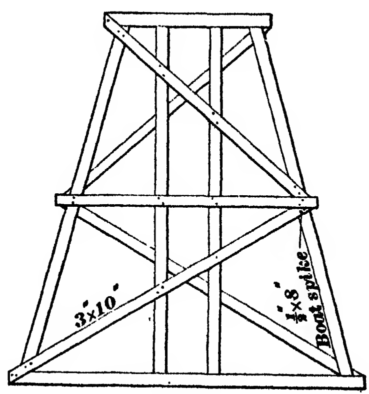


FIG. 57

other, they are spiked with $\frac{1}{2}'' \times 8''$ boat spikes. Bolt fastenings may be easily removed without damaging the braces, which may be used a second time, if not decayed. Spikes, on the other hand, are difficult to draw, and sway-braces are often split or broken in removing them from the bents. However, second-hand trestle material is of little value, and, as spikes are a sure fastening and are cheaper and more expeditious than bolts, they are to be recommended.

When the piles of a bent are out of line, so that the sway-brace cannot lie flat, they should be hewn so that the sway-brace will come in direct contact with every pile or post, or else a packing piece of the necessary thickness should be placed under the sway-brace to give it a full bearing on the bent.

35. Counter-Posts.—Framed bents exceeding a height of 30 feet are frequently stiffened by counter-posts as shown by *a b* and *c d*, Fig. 70. Counter-posts require the dividing up of the bent into two or more stories by means of an intermediate sill *e f*, and are generally employed in high work, where two and sometimes three sets of counters are used.

36. Longitudinal Bracing.—Longitudinal bracing is employed in various ways. Some constructors brace every bay or span; others, every third or fourth bay. In some trestles, the bracing is placed diagonally; in others, horizontally; while in some both forms are used. Fig. 69 shows the laced form of longitudinal bracing as employed by the Pennsylvania Railroad. The caps and sills are chamfered, and the braces cut to fit them, as shown in the detail at *A*. The braces are fastened to both cap and sill by heavy cut spikes.

37. Lateral Bracing.—Lateral bracing, shown at *a b*, Fig. 71, adds much to the stiffness of a structure. These braces are usually of $6'' \times 6''$ timber, bolted together at their intersection *c* with either $\frac{5}{8}$-inch or $\frac{1}{2}$-inch bolts. They are slightly notched into the caps, to which they are fastened, with heavy cut spikes. They contribute much toward keeping the track in line, and serve to a considerable extent the purpose of longitudinal bracing. Whatever the style of

bracing employed, it must be borne in mind that the effectiveness of bracing depends largely on the thoroughness with which it is fastened to the parts to be strengthened. Sway-bracing is usually fastened to the cap and sill with ¾-inch bolts, and spiked to the posts or piles with boat spikes. Diagonal braces, especially those framed or notched into the bent timber, are frequently found loose and ineffective. When spiked or bolted to place, they should fit snugly and be at least slightly strained.

38. Trestles on Curves.—Wherever possible, curved trestles should be avoided. The additional stress due to the centrifugal force of heavy trains at high speed is a severe tax on the structure, and the locating engineer should, if possible, so modify his line as to place all trestles on tangents. Circumstances, however, sometimes render the curved trestle a necessity, in which case the outer posts must have an increased batter and the outer rail its proper elevation.

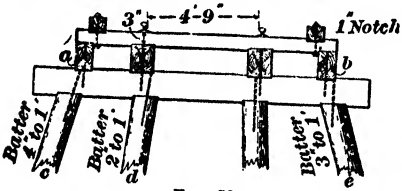


FIG. 58

There are various methods of elevating track on curved trestles, three of which are shown in Figs. 58, 59, and 60. In Fig. 58, the elevation is effected by cutting off the piles or framing the posts to such lengths as will afford the requisite elevation. This is the simplest and easiest method of elevating the outer rail of a trestle. There are no shims to get out of place or that will need renewing, and there is no increase in cost above that of a trestle on a straight line.

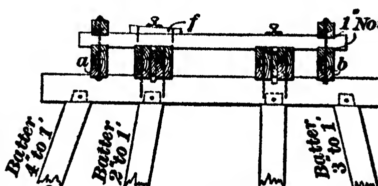


FIG. 59

In Fig. 59, the outer rail is elevated by means of a shim *f*, which is placed under the rail and fastened to the tie with cut spikes. The weak point in this mode of elevating the outer rail, aside from the cost of making and fastening the

shims, is the accumulation of moisture under the shims, which induces their decay and the decay of the ties also.

In Fig. 60, the elevation is effected by cutting away a portion of the cap at *a* to an amount equal to the required elevation. The stringers are then placed in a horizontal position, as shown in the figure, and the notches in the ties beveled so as to fit the top of the stringers.

In pile bents, the caps are usually drift-bolted to the piles; in framed bents, the connection is usually made with mortise and tenon. In all three methods, the stringers are drift-bolted to the caps. In Figs. 58 and 59, the jack-stringers *a* and *b* add considerably to the stability of the structure, and are an additional safeguard in case of derailment. Both posts or piles *c*, *d* on the outside of the curve are battered, the outside one at a batter of 4 inches to the foot, and the next inside, at 2 inches to the foot. On the inside of the curve, only the outside posts or piles *e* of the bent are battered, at the usual batter of 3 inches to the foot. If the trestle is a high one, it should be strengthened by additional bracing.

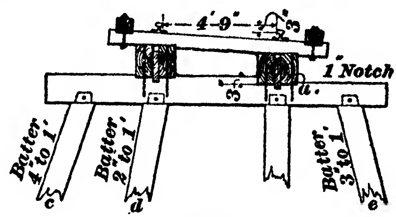


FIG. 60

DETAILS AND SPECIFICATIONS

DETAILS

SPIKES, BOLTS, ETC.

39. Spikes.—There are two kinds of spikes used in trestle building; namely, **cut spikes**, Fig. 61, which are formed like ordinary cut nails and manufactured in the same way; and **boat spikes**, Fig. 62, which are forged from bars of wrought iron. Spikes of the same length are not necessarily of the same weight. Slender spikes are not suited for trestle building, as they are likely to bend and break, and are besides lacking in holding power. Those having good-sized heads and bodies should always be used. Steel spikes are to be preferred to iron ones, as they are tougher and stronger. Boat spikes, shown in Fig. 62, have strong, well-formed heads, and are *chisel-pointed*. They are used to fasten guard-rails to ties, ties to stringers, and sway-bracing to bents.

FIG. 61

FIG. 62

40. Drift Bolts.—Drift bolts commonly resemble boat spikes in shape, but are much larger, and their heads are less carefully shaped. Very often the bolts are used without either head or point, being simply sheared from rods to a proper length, and driven into the holes bored to receive them. The ordinary shapes are shown in Fig. 63. For fastening 12-inch caps to posts or piles, drift bolts of $\frac{3}{4}$-inch square or $\frac{3}{4}$-inch round iron, and 20 inches long, are commonly used. They should always penetrate the last timber into which they are driven far enough to resist any usual pull or shock that may

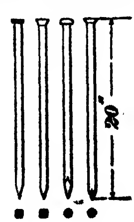


FIG. 63

be placed on them. Holes are always bored to receive drift bolts; they should be of such size that, in driving, the fibers of the wood will fill all space not occupied by the bolt itself.

41. Dowels.—In place of drift bolts, short iron rods, either square or round, called **dowels**, are frequently used. They have neither point nor head, but are sheared from rods, care only being taken to make them straight. They are frequently used to fasten caps to posts, posts to sills, and ties to stringers. A common size of dowel for fastening caps to posts and posts to sills is $\frac{3}{4}$ inch round or square by 8 inches long, and weighing about 1 pound each.

Dowels of $\frac{5}{8}$-inch round iron, 5 inches in length, are well suited for fastening ties to stringers.

42. Bolts.—Bolts for holding the stringer pieces together and fastening the braces, guard-rails, etc. are commonly of $\frac{3}{4}$-inch round iron, their lengths, of course, depending on the purpose for which they are to be used. The bolt heads should be well formed and of good weight, and the threads right-handed and well cut. Square nuts with a thickness equal to the diameter of the bolt and a length of side equal to twice the diameter of the bolt are the best. The outer top corners of both head and nut should be chamfered.

A cast-iron washer from 3 to $3\frac{1}{2}$ inches in diameter should be placed under the head and nut of all bolts. To insure a close fit, holes of $\frac{1}{16}$ inch less diameter than the bolts are bored through the timber to receive them.

In ordering bolts, the term *grip*, as sometimes employed, signifies the total thickness of the material to be held together—in other words, the distance between the inside faces of washers.

43. Lagscrews.—A **lagscrew**, Fig. 64, is a large screw used instead of a bolt. The head is shaped like a bolt head, and an ordinary wrench may be used in putting the screw in place. A hole of the full size of the shank of the screw is bored through the first timber, and a much smaller one is bored for the rest of the distance through which the thread is to pass. A

FIG. 64

wrought or punched washer cut from sheet iron should be placed under the head of each lagscrew.

44. Washers.—Cast washers are largely used in trestle building. One should be placed under the head and nut of every bolt used in the structure. The more common forms of cast washers are shown in Fig. 65. The solid washers are placed under the head, and the slotted washers, or those having a second hole, under the nut. The purpose of the

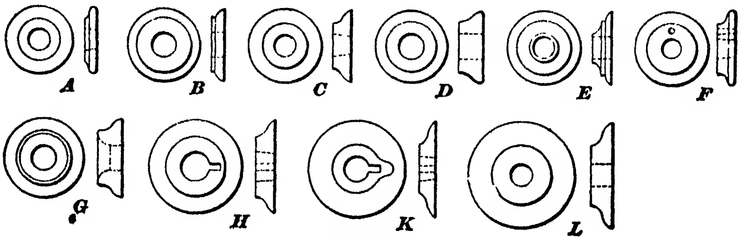


FIG. 65

slot, or second hole, is to provide for locking the nut. After the nut is well tightened, a nail is driven in the slot or hole, with the head projecting far enough above the face of the washer to permit of its being drawn with a claw hammer. This effectually locks the nut. Wrought nuts may be effectually locked by nicking the thread with a center punch after the nut has been screwed home.

CONNECTION WITH EMBANKMENT

45. Abutments for Trestles.—The profile of the natural surface immediately under a trestle has, at the ends of the trestle, banks that are comparatively steep. The trestle is generally designed so that the first trestle bent will have a considerable height (10 feet or more), and then there will be a single span of perhaps 15 feet between that trestle bent and the abutment. In some of the best work, the abutment is a masonry wall such as might serve for the abutment of a smaller bridge; in other cases, a crib having a somewhat different form from the crib described in Art. 18

is used; and in other cases, a bank bent is employed, as will be explained presently.

46. Crib Connection.—The crib is usually built of 12″ × 12″ timbers halved one into the other and drift-bolted at each intersection of the timbers. There are several

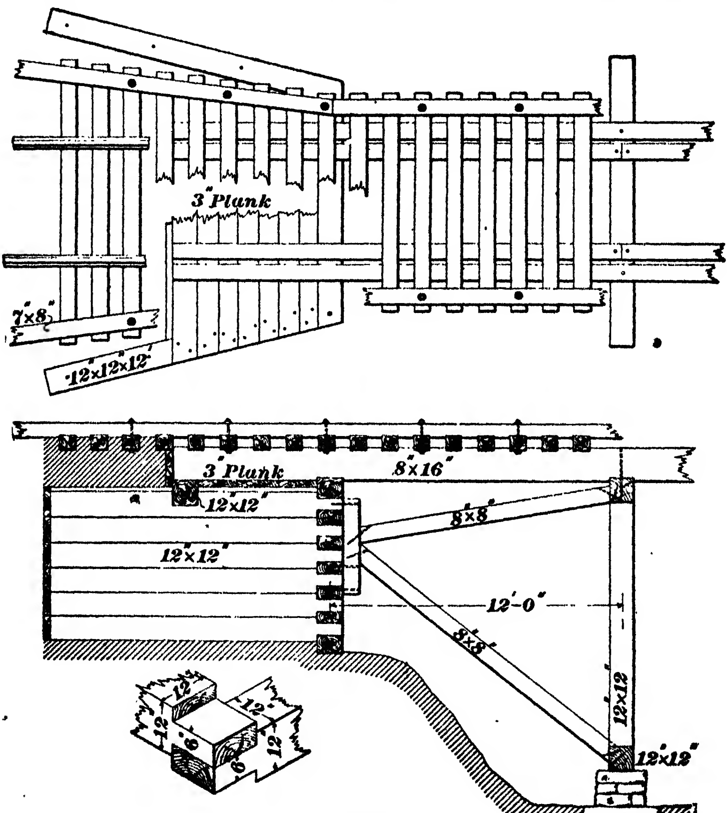


FIG. 66

courses of timbers, according to the height of the embankment. The building of the crib should be deferred until the rest of the trestle is completed, so as to allow time for the settlement of the embankment. Before commencing the crib, a space of ample size to receive it should be excavated from the end of the embankment, and the earth should be

well rammed for a foundation before the timbers are put in place. The proper elevation for this foundation should be determined by the engineers, so that the top of the crib may have the proper elevation without making it necessary to hew away any of the timber. The timbers composing the front of the crib—that is, the part facing the trestle—should be at least 10 feet long, and those parallel to the track, of equal length. The top of the crib should be fixed exactly at grade, so that trains may pass from the embankment to the trestle, and vice versa, without any jolting. Timbers frequently vary $\frac{1}{2}$ inch in thickness, so that the actual elevation of the top of the crib may vary 1 inch or 2 inches from the calculated elevation. This discrepancy may be easily remedied by shims, if the top of the crib is too low, and by notching down the stringer, if the top is too high. It is well to have the stringers extend back from the face of the crib several feet. The bottoms of the stringers should be kept from coming in contact with the earth of the embankment. This may be accomplished by spiking planks to the crib timbers underneath the stringers. The stringers should be drift-bolted to the crib timbers. The skeleton construction for the cribwork and a filling of broken stone, as described in general in Art. 18, would be preferable to the method illustrated in Fig. 66, since there would be less liability to decay.

47. Bank-Bent Connection.—Connection between the embankment and the trestle may be made by means of a **bank bent,** either of piles or framed. This construction, which is illustrated in Fig. 67, is more favored than the crib form previously described. It consists of a strong frame or pile bent built into the slope at the end of the embankment for the support of the stringers. If piles are used, the bent should contain four piles deeply driven into the embankment, so that they will not only safely carry the train load, but will sustain the pressure of the back filling, which is carried up to the base of the stringers. To hold this piling in place, the back of the bent is close planked with 3-inch or 4-inch plank. When the bank bent is of considerable height, struts

of 8″ × 8″ timber should extend from the bank bent to the timbers of the first trestle bent, to insure its stability. When the bank bent is of framed timber, special pains

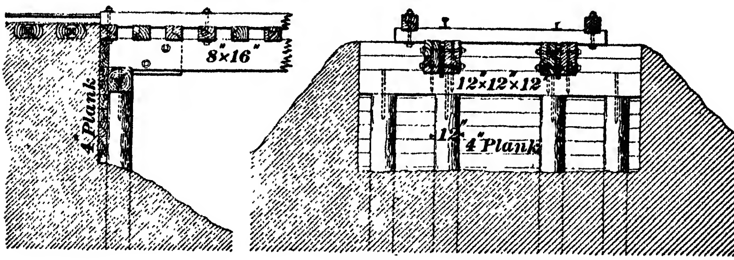


FIG. 67

should be taken to insure a safe foundation for the sill. Sub-sills of 12″ × 12″ timber, laid in trenches, form a good foundation. Before laying the sub-sills, the ground should be thoroughly rammed to prevent settlement.

REFUGE BAYS, FOOTWALKS, AND FIRE-PROTECTION

48. Refuge Bays.—On all trestles of a length of 200 feet or more, **refuge bays** should be built where workmen or trackwalkers can find safety when overtaken by a train. They consist of small projecting platforms supported by ties having the necessary additional length. A refuge bay of approved pattern is shown in Fig. 68. On trestles of a length exceeding 1,000 feet, every fourth refuge bay should be large enough to contain a hand car and section gang. While repairs are being made on a trestle, before work is commenced, the hand car, together with all idle tools, should be placed in a refuge bay, and should remain there until the work is finished.

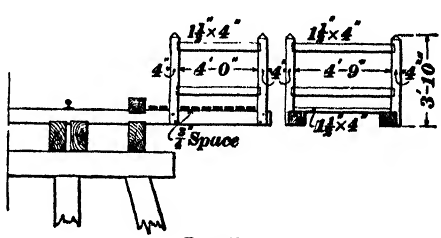


FIG. 68

49. Footwalks.—On some roads, it is customary to place between the rails a footwalk of 1-inch boards from 1 to 2 feet in width. This is a bad plan, for it encourages the public to use a trestle as a thoroughfare on account of the ease in crossing it; it increases the danger of fire, as the walk forms a lodgment for coals dropped from the fireboxes of the engines, and it tends to careless inspection on account of the difficulty of reaching the parts of the structure that are covered by the walk.

50. Fire-Protection.—Every trestle should be provided with the means of protection against fire. This is sometimes effected by covering the tops of ties and stringers with sheet iron. Another method of protection is afforded by water stored in tubs at intervals of not more than 200 feet, and provided either with buckets or large dippers. The buckets should be of metal, wood pulp, or paper; metal well painted is preferable. The trackwalker should examine all tubs at least once each week and report their condition to the section foreman, whose business it is to keep them full of water. Kerosene barrels sawed in two make excellent tubs, being cheap and enduring.

An equally important safeguard against fire is the cutting and burning of all grass and brush from the right of way adjacent to the trestle, and the removal and burning of all rubbish that could afford any lodgment for sparks. The grass and brush should be cut early in the season, when the stubble is too green to burn.

It is the contractor's business to protect the trestle against fire during construction by the removal and burning of all brush and rubbish that can in any way threaten its safety. A clause to this effect should have a place in every contract.

FIELD WORK

51. Locating Bents.—The number of bents composing the trestle and the number of the station at the beginning and at the end of the trestle are determined from an inspection of the profile. The center line of the trestle is then run

in, a plug being driven on the center line locating each bent. It is customary to place these center plugs 1 foot in advance of the bent centers, so that they will not be disturbed while the bents are being placed in position. The center plugs having been driven, the transit is set up at each plug and stakes are set at right angles to the center line, giving the direction of the sill. These stakes are, like the center plug, 1 foot in advance of the required center line of the sill. In case the trestle is built on a curve, the bents should stand on radial lines.

It is of the first importance that the levels be correct, and to facilitate the checking of them, a bench mark should be established at the end of the trestle, and another near the lowest point of the line over which the trestle passes. At the center plug, a strong stake should be driven, having its top level with the top of the foundation for that bent. One grade stake at each bent is sufficient, as the workmen can transfer that elevation to other points, if necessary, with an ordinary carpenter's or mason's level.

52. Erecting.—Trestle bents of moderate height are framed lying flat on the ground, with the sills so placed that when the bent is raised it will occupy its proper position. The raising is effected by means of blocks and a fall, the power being ordinarily applied by either horses or a gang of men. The end bent is first raised and braced in position, and the tackle for raising the next bent attached to it. Before a bent is raised, stay-ropes should be attached to it to give it steadiness and prevent it from being pulled over after reaching an upright position. As soon as a bent is raised, it should at once be fastened in position by means of **stay-lath** nailed to it and the bent immediately preceding. The sway-bracing should be fastened immediately, and when no longitudinal bracing is to be added, the stringers should be put in place and fastened before another bent is raised.

High trestles, composed of several sections placed one above the other, and separated by purlins (see Fig. 72), are usually erected as follows: The bottom deck having been

raised, the purlins are arranged on it, and a temporary floor is laid on the purlins, on which the bent forming the next section is placed and raised precisely as though it lay on the ground.

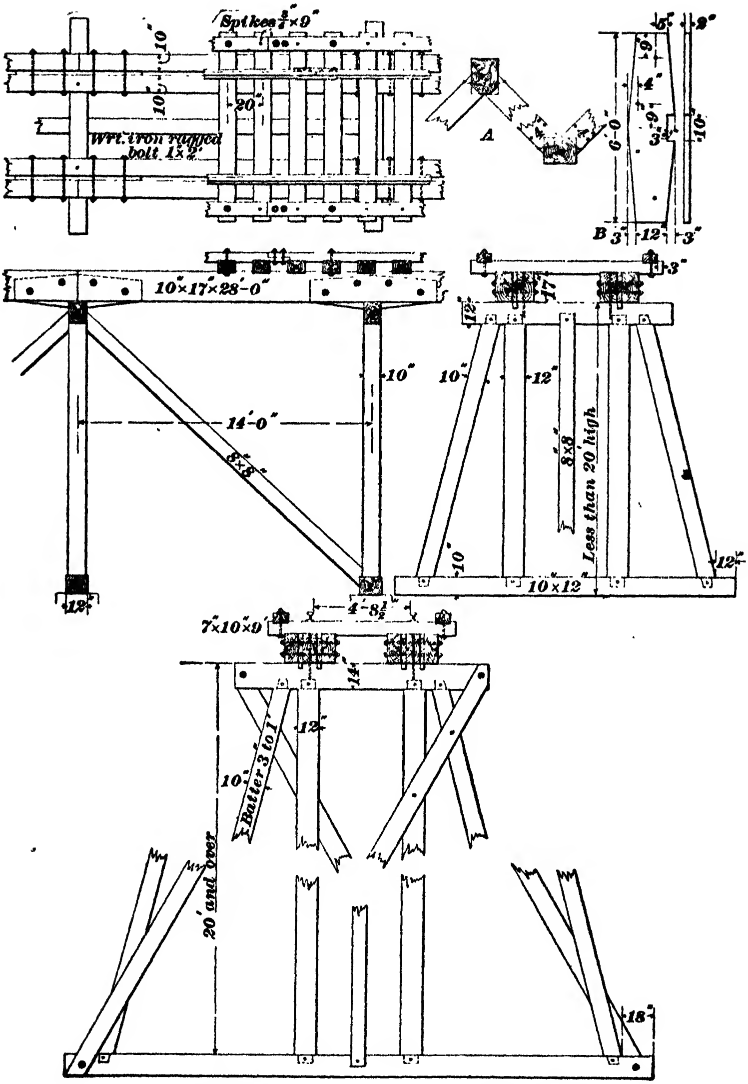
Special designs require special methods, but the plan generally adopted is the one just given. A tack or nail is driven in each cap on the center line for the accurate placing of the stringers. After the ties and guard-rails are in place and fastened, tacks are driven in ties at intervals of about 50 feet, to guide the tracklayers.

53. Preservation of Joints.—At every point where two pieces of timber come in contact, they should be painted with some preservative material. As trestle timbers are usually rough, a considerable quantity of material is necessary, if all joints are to be properly treated. White lead, though effective, is too expensive. Hot coal tar is a cheap and effective wood antiseptic, and available everywhere. Creosote oil is also much used, and when the finances of the company permit it, a trestle built of timber that has been thoroughly treated with creosote oil under pressure is undoubted economy.

STANDARD AND HIGH TRESTLES

54. Standard Plans for Trestles.—In Figs. 69, 70, and 71 are shown, in complete detail, several standard plans for trestles. These details should be studied closely as examples of details that have been previously described.

55. High Trestles.—Very high trestles call for the best engineering skill and a special design. Recent practice has modified considerably many details that are so common in ordinary trestles. More iron is introduced and less framing. Posts and sills are fastened together with dowels instead of with mortise and tenon; braces are fastened with bolts, and, wherever possible, the cutting of timber incident to framing is avoided. The braces are increased in size and reduced in number. Instead of short braces framed into the posts at each angle, long braces,

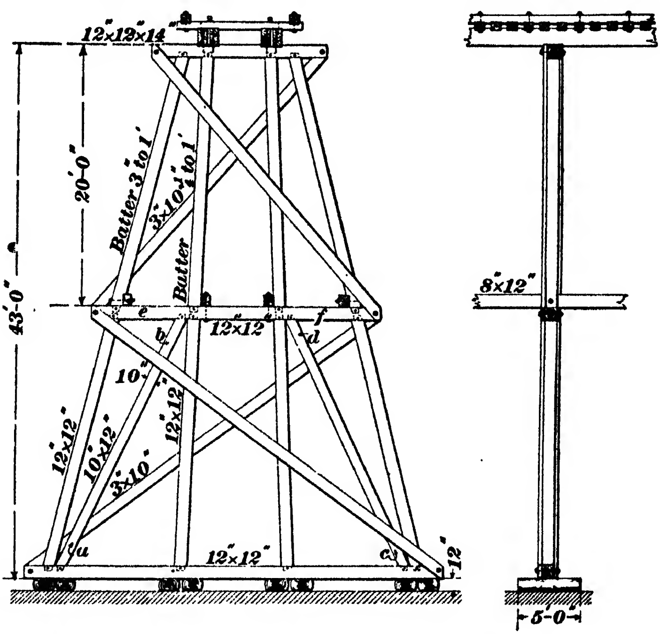


Standard Framed Trestle, Pennsylvania Railroad

Fig. 69

reaching from one-half to the total width of the bent, are bolted to the main timbers. By this means, the strains due either to the wind pressure or the train load are distributed throughout the structure.

The trestle shown in Fig. 72 is a copy of one built on the line of the Oregon & Washington Railroad. Its height from ground to rail is about 100 feet. A trestle of this design is very simple and strong. By battering the inside posts,

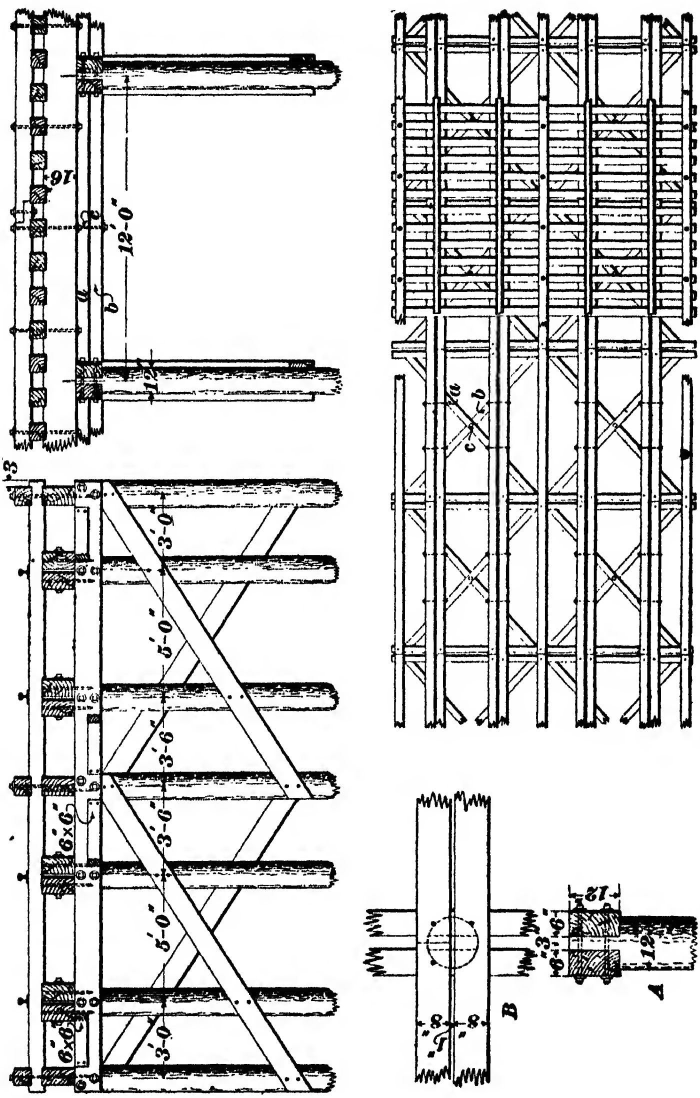


STANDARD FRAMED TRESTLE, OHIO CONNECTING RAILWAY

FIG. 70

the load is well distributed over the base, which has sufficient breadth to insure stability. The system of sway-bracing is exceptionally good. The horizontal wales *a*, *b*, and *c*, which are bolted to the posts, practically double the number of decks and reduce the post lengths to one-half their actual length. They also form seats for the purlins *d*, *f*, and *h*.

Each bent consists of three sections of equal height, separated by eight 12″ × 12″ purlins *e*, *g*. These purlins extend



STANDARD DOUBLE-TRACK PILE TRESTLE, BOSTON & ALBANY RAILROAD

FIG. 71

longitudinally the length of two bents, breaking joints like stringers, and form decks on which the successive sections rest. The purlins are notched down 1 inch on the caps, and

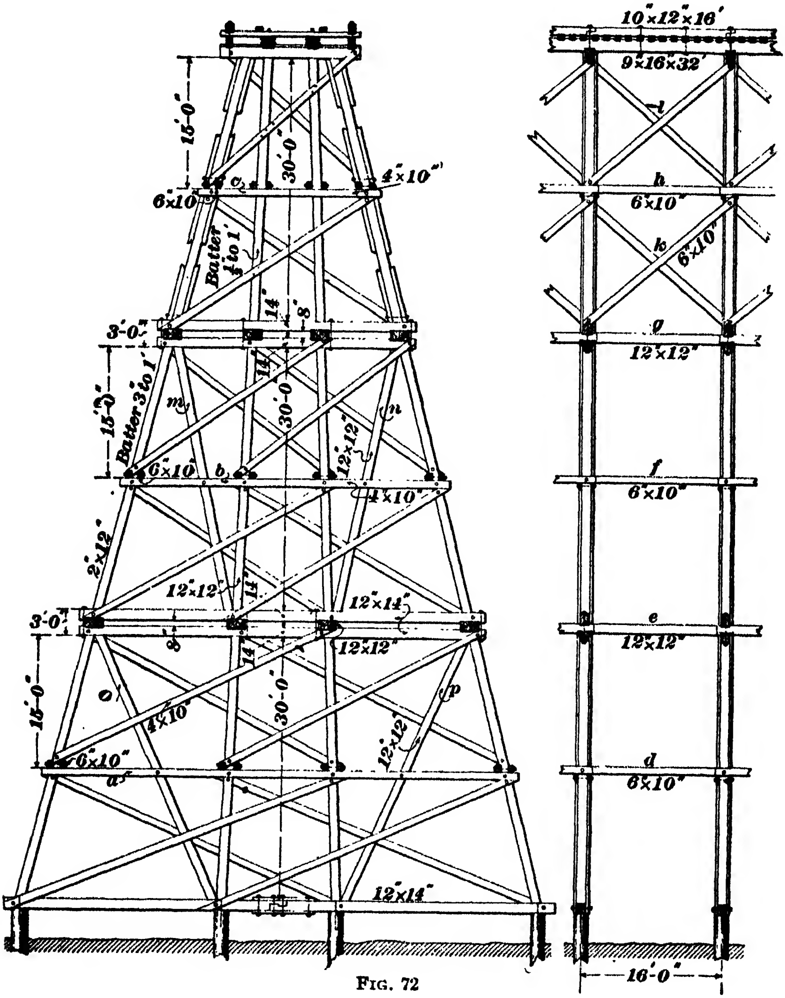


Fig. 72

are also notched 1 inch to receive the sills of the bent resting on them. The caps and sills of succeeding sections are bolted together. The purlins constitute the entire longitudinal

bracing, except in the upper section, where diagonal braces *k*, *l* are employed. It would add considerably to the stability of the structure if similar braces were placed in every panel from the ground upwards. The plan shows but one dowel at each connection of post with sill. Two would be a better number, especially in the case of the outside batter posts and the counter-posts *m*, *n*, *o*, and *p*.

TRESTLE DESIGN

56. Trestles can be designed by the same general principles that are used in the design of bridges and roof trusses. Nearly all railroads, however, have standard sizes of timber that they use for the construction of all trestles, regardless of any special conditions. Thus, 12″ × 12″ timber is commonly adopted as a standard size for posts, caps, and sills. The adoption of these uniform sizes, which experience has shown to be more than ample, is defended on the ground that the construction department can do their work best by employing uniform sizes of trestle stuff. When any trestle is needed, especially a temporary trestle that must be constructed with great rapidity after a bridge has been wrecked, several car loads of trestle stuff of all lengths and sizes can be rushed to the spot, and the trestle put up in a short time. Under such special circumstances, the employment of uniform sizes has its undoubted advantages; and, under all circumstances, it saves the work and expense of designing every trestle by itself. Where timber is scarce or expensive, however, it may sometimes prove economical to make a careful calculation of the sizes that are actually necessary. And even where standard sizes are used, they should not be adopted arbitrarily, but should be so chosen or designed that the structure will be safe under the most unfavorable conditions.

SPECIFICATIONS FOR WOODEN TRESTLES

57. The following specifications are general, but are sufficiently detailed to guide in making an application to any particular structure. Special conditions may make it necessary to omit or change some of the items or to insert new ones.

58. Clearing.—Before beginning work on any structure, the ground must be entirely cleared of logs, stumps, trees, and brush of every description. All combustible material must be piled at convenient places and completely burned. Trees outside the right of way that, by falling, may endanger the trestle, must be felled by the contractor, it being understood that permission to fell such trees shall be obtained by the railroad company from the landowner. Such portions of the right of way as shall be deemed necessary by the engineer shall be grubbed.

59. Drawings.—The drawings are to the scale indicated and marked; but in all cases the figures are to be taken, and, in case of omission, the engineer in charge is to be referred to for dimensions. Under no circumstances are the drawings to be scaled either by the contractor or by any of his men. The engineer will be required to mark the dimensions on the contractor's blueprint and keep a record of the same in his office.

60. Dimensions.—All posts, braces, clamps, stringers, packing-blocks, ties, guard timbers, sills, and all timber generally shall be of the exact dimensions given and figured on the plan. Variations from these will be allowed only on the written consent of the engineer in charge.

61. Timber.—All timber shall be of good quality and of such kinds as the engineer shall direct, and be free from wind shakes, black, loose, or unsound knots, worm holes, and all signs of decay. It must be sawed true, and out of wind, and full size. Under no circumstances shall any timber cut from dead logs be allowed to be placed in any part of the structure; all timber must be cut from living trees.

62. Piles.—Piles shall be cut from live, thrifty timber. They will be either round or square, as may be required by the engineer. Round piles must be straight, be stripped of all bark, and be well trimmed. They must be at least 12 inches in diameter at the cut-off when cut to grade to receive the cap. The smaller end must be at least 8 inches in diameter.

Square piles must be hewn (or sawed) 12 inches square. They must have at least 9 inches of heart wood on each face from the head of the pile after being cut off to grade, to 5 feet below the surface of the ground into which the pile is driven.

All piles must be properly pointed. They shall, if required, be shod with shoes of cast or wrought iron, made according to plans furnished by the engineer. In driving, they shall be banded with wrought-iron rings of suitable weight to prevent splitting. The actual cost, delivered on the ground, of the necessary shoes and rings will be allowed to the contractor. Piles must be driven to hard bottom or until they do not sink more than 5 inches under the last five blows from a hammer of at least 2,000 pounds weight falling free 25 feet. All piles damaged in driving, or driven out of place, shall be either withdrawn or cut off, as the engineer may direct, and others driven in their stead. The piles thus replaced will not be paid for. All piles under track stringers must be accurately spaced and driven vertically, and in each bent the batter piles must be driven at the angle shown.

Piles shall be measured by the lineal foot after they are driven and cut off, and the price per lineal foot shall be understood to cover the cost of transportation, removing the bark, driving, cutting off, and all labor and materials required in the performance of the work, but that portion of each pile cut off shall be estimated and paid for by the lineal foot as "piles cut off."

The contractor must give all facilities in his power to aid the pile recorder in his duties.

Parts of pile heads projecting beyond the cap must be adzed off at an angle of 45°.

63. Framing.—All framing must be done to a close fit and in a thorough and workmanlike manner. No blocking or shimming of any kind will be allowed in making joints, nor will open joints be accepted.

All joints, ends of posts, piles, etc., and all surfaces of wood on wood shall be thoroughly painted with hot creosote oil and covered with a coat of thick asphaltum, hot asphaltum, or hot common tar; or they shall be given a good thick coat of white lead ground and mixed with pure linseed oil.

All bolt and other holes bored in any part of the work must be thoroughly saturated with hot creosote oil, hot asphaltum, hot tar, coal tar, white lead mixed with pure linseed oil, or linseed oil.

All bolts and drift bolts before being put in place must be warmed and coated with hot creosote oil, hot asphaltum, hot tar, or hot coal tar; or they shall be coated with white lead and linseed oil.

All bolt holes for bolts $\frac{3}{4}$ inch in diameter or over must be bored with an auger $\frac{1}{8}$ inch smaller in diameter than the bolt, in order to

secure a perfectly tight fit of the bolt in the hole. For bolts $\frac{5}{8}$ inch in diameter or smaller, the auger must be $\frac{1}{16}$ inch smaller.

64. Trestles on Curves.—Trestles built on curves must have the outer rail elevated according to plans furnished from the chief engineer's office, a copy of which will be delivered to the contractor.

65. Creosoted Trestles.—All piles used in creosoted trestles must be completely stripped of bark, and be pointed before treatment. None of the sap wood may be hewn from the piles. No notching or cutting of the piles will be allowed after treatment, except the sawing off of the head of the pile to the proper level for the reception of the cap, and the beveling of such part of the head as shall project from under the cap.

The heads of all creosoted piles, after the necessary cutting and trimming has been done for the reception of the cap, must be saturated with hot creosote oil, and then covered with hot asphaltum before the cap is put in place.

Timber for creosoted trestles must be cut and framed to the proper dimensions before treatment. No cutting or trimming of any kind will be allowed after treatment, except the boring of the necessary bolt holes.

Hot creosote oil must be poured into the bolt holes before the insertion of the bolts, in such a manner that the entire surface of the holes shall receive a coating of the oil.

66. Treatment of Creosoted Piles and Timber.—All creosoted timber and piles shall be prepared in accordance with the following process: The timber and piles, after having been cut and trimmed to the proper size and shape, shall be submitted to a contact steaming inside the injection cylinders, which shall last from 2 to 3 hours, according to the size of the timber; then, to a heat not to exceed 230° F., in a vacuum of 24 inches of mercury, for a period long enough to dry the wood thoroughly. The creosote oil, heated to a temperature of about 175°, shall then be let into the injection cylinder and forced into the wood under a pressure of 150 pounds per square inch, until not less than 15 pounds of oil to the cubic foot has been absorbed. The oil must contain at least 10 per cent. of carbolic and cresylic acids, and have at least 12 per cent. of naphthalene.

67. Iron.—(*a*) *Wrought Iron.*—All wrought iron must be of the best quality of American refined iron, tough, ductile, and uniform in quality, and must have an elastic limit of not less than 26,000 pounds per square inch.

All bolts must be perfect in every respect, and have nuts and threads of the full standard size corresponding to their diameters. The thickness of the nut shall not be less than the diameter of the bolt, and the side of its square not less than twice the diameter of the bolt.

The heads of all bolts shall be square, round button, or countersunk. (1) When square, the thickness shall not be less than the diameter of the bolt, and the side of its square not less than twice the diameter of the bolt. (2) When round button, the thickness at center shall not be less than three-quarters of the diameter of the bolt, and the extreme diameter not less than two and one-half times the diameter of the bolt. (3) When countersunk, the extreme diameter of head shall not be less than twice the diameter of the bolt, and it shall be countersunk on the under side so as to fit into a cup washer.

(*b*) *Cast Iron.*—All castings must be of good tough metal, of a quality capable of bearing a weight of 550 pounds, suspended at the center of a bar 1 inch square, and $4\frac{1}{2}$ feet between supports. They must be smooth, well-shaped, free from air holes, cracks, cinders, and other imperfections.

All iron must be thoroughly soaked in boiled linseed oil before leaving the shop.

68. Inspection and Acceptance.—All materials must be subject to the inspection and acceptance of the engineer before being used. The contractor must give all proper facilities for making such inspection thorough.

Any omission by the engineer to disapprove the work at the time of a monthly or any other estimate being made shall not be construed as an acceptance of any defective work.

69. Protection Against Fire.—The contractor must, each evening before quitting work, remove all shavings, borings, and scraps of wood from the deck of the trestle and from proximity to the bents, and on the completion of the work must take down and remove to a safe distance all staging used in the erection of the work, and remove and burn all fragments of timber, shavings, etc.

70. Roads and Highways.—Commodious passing places for all public and private roads shall be maintained in good condition by the contractor, and he shall open and maintain thereafter a good and safe road for passage on horseback along the whole length of his work.

71. Running of Trains.—The contractor shall so conduct all his operations as not to impede the running of trains or the operation of the road. He will be responsible to the railroad company for all damages to rolling stock or damages from wrecks caused by his negligence. The cost of such damage will be retained from his monthly and final estimates.

72. Risks.—The contractor shall assume all risks from floods, storms, and casualties of every description, except accidents caused by the railroad company, until the final estimate of the work.

73. Labor and Material.—The contractor must furnish all labor and material incidental to or in any way connected with the manufacture, transportation, erection, and maintenance of the structure until its final acceptance.

Disorderly, quarrelsome, or incompetent men in the employ of the contractor, or those who persist in doing bad work in disregard of these specifications, must be discharged by the contractor when requested to do so by the engineer.

Whenever the chief engineer may deem it advisable, he may name the rates and prices to be paid by the contractors, for such time as he may designate, to the several classes of laborers and mechanics in their employ, and for the hire of horses, mules, teams, etc., and these shall not be exceeded; and having given due notice to the contractors of his action in regard to these matters, the contractors shall be bound to obey his orders in relation thereto. The chief engineer shall not, however, name a rate or price for any class of labor, etc. higher than the maximum rates being paid by the contractor paying the highest for that class.

74. Damages and Trespass.—Contractors shall be liable for all damages to landholders, arising from loss of or injury to crops or cattle, sustained by any cause connected with the works or through any of the contractors' agents or workmen. Contractors shall not allow any person in their employ to trespass on the premises of persons in the vicinity of the works, and shall, at the request of the engineer, discharge from their employ any person that may be guilty of committing damage in this respect. They shall also maintain any fences that may be necessary for the protection of any property or crops.

75. Removal of Defective Work.—The contractor must remove at his own expense any material disapproved by the engineer, and must remove and rebuild, without extra charge and within such time as may be fixed by the engineer, any work appearing to the engineer, during the progress of the work or after the completion, to be unsound or improperly executed, notwithstanding that any certificate may have been issued as due for the execution of the same. The engineer shall, however, give notice of defective work to the contractor as soon as he shall have become cognizant of the same. On default of the contractor to replace the work as directed by the engineer, such work may be done by the railroad company at the contractor's expense.

76. Delays.—No charge shall be made by the contractor for hindrances and delay, from any cause, in the progress of the work; but it may entitle him to an extension of the time allowed for completing

the work, sufficient to compensate for the detention, to be determined by the engineer, provided he shall give the engineer in charge immediate notice, in writing, of the detention.

77. Extra Work.—No claim shall be allowed for extra work, unless done in pursuance of a written order from the engineer, and unless the claim is made at the first estimate after the work is executed. The chief engineer may, at his discretion, allow any claim, or such part of it as he may deem just and equitable.

Unless a price is specified in the contract for the class of work performed, extra work will be paid for at the actual cost of the material remaining in the structure after its completion and the cost of the labor for executing the work, plus 15 per cent. of the total cost. This 15 per cent. will be understood to include the use and cost of all tools and temporary structures, staging, etc., and the contractor's profit, and no extra allowance over and above this will be made.

78. Information and Force Accounts.—The contractor shall aid the engineer in every way possible in obtaining information, and freely furnish any which he may possess, by access to his books and accounts, in regard to the cost of work, labor, time, material, force account, and such other items as the engineer may require for the proper execution of his work, and shall make such reports to him from time to time as the engineer may deem necessary and expedient.

79. Prosecution of the Work.—The contractor shall commence his work at such points as the engineer may direct, and shall conform to the engineer's directions as to the order of time in which the different parts of the work shall be done, as well as the force required to complete the work at the time specified in the contract. In case the contractor shall refuse or neglect to obey the orders of the engineer in the above respects, the engineer shall have the power to either declare the contract null and void and relet the work, or to hire such force and buy such tools at the contractor's expense as may be necessary for the proper conduct of the work, as may in his judgment be for the best interests of the railroad company.

80. Changes.—At any time during the execution or before the commencement of the work, the engineer shall be at liberty to make such changes as he may deem necessary, whether the quantities are increased or diminished by such changes, and the contractor shall not be entitled to any claim on account of such changes beyond the actual amount of work done according to these specifications at the prices stipulated in the contract, unless such work is made more expensive to him, when such rates as may be deemed just and equitable by the chief engineer will be allowed him; if, on the other hand, the work is made less expensive, a corresponding deduction may be made.

81. Quantities.—It is distinctly understood that the quantities of work estimated are approximate, and the railroad company reserves the right of building only such kinds and quantities, and according to such plans, as the nature or economy of the work may in the opinion of the engineer, require.

82. Engineer.—The term **engineer** will be understood to mean the chief engineer, or any of his authorized assistants or inspectors, and all directions given by them, under his authority, shall be fully carried out by the contractor and his agents and employes.

83. Price and Payment.—The prices bid will include the furnishing of materials, tools, scaffolding, watching, and all other items of expense in any way connected with the execution and maintenance of the work until it is finally accepted and received as completed. The contractor shall be paid only for the piles, timber, and iron left in the structure after completion. No wastage in any kind of material will be paid for except in the case of piles, when the "piles cut-off," which cannot be used on any other part of the contractor's work, will be paid for at the rate agreed on. After the material cut off is paid for, it is to be considered the property of the railroad company, and is to be neither removed nor used by the contractor without the consent of the engineer, and then only on the repayment of the price which has been paid for it.

The piles and "piles cut-off" will be paid for by the lineal foot, the former driven in place.

The timber and lumber remaining in and necessary to the completed structure will be paid for by the thousand feet, board measure.

The iron remaining in the structure after its completion will be paid for by the pound.

The masonry for foundations will be paid for by the cubic yard.

The excavations for foundations will be paid for by the cubic yard.

The retained percentage will not be paid on the cost of any single structure until the *final estimate* is due on the entire work embraced in the contract.

TRACKWORK

(PART 1)

TRACK PARTS AND MATERIALS

BALLAST

1. Subgrade.—When the earthwork on a new railroad, including the cuts, embankments, side ditches, etc., has been finished, an even graded surface, called the **subgradge,** is obtained on which the track will be laid. The position of the subgrade is shown by the lines *bc* in Figs. 14 and 17.

2. Ballast.—The ties are not laid directly on the subgrade, because the natural soil is not firm enough nor of sufficiently uniform bearing power to keep the rails in alinement when heavy loads pass over them. As, besides, it is not possible to secure perfect drainage of the subgrade itself, the alternate thawing and freezing of the soil will soon force the track out of position. For these reasons, a layer of broken stone, gravel, or other material is laid on the subgrade, and on this the ties are placed; this layer is called **ballast.**

The materials used for ballast, given in the order of their value, are: *broken stone*, *gravel*, *cinders*, *slag*, *shells*, and *natural soil* or *mud.*

3. Broken Stone.—Broken stone is the standard ballast for high-speed first-class roads. It is the most expensive of all ballast in its first cost, but for heavy traffic it keeps the track in place better than any other form of ballast. It is

generally specified that the stone shall be broken to such a size that it will pass through a 1½-inch, or sometimes a 2-inch, ring. Until within a few years, the stone was broken by hand; and, even after stone crushers came into use, it was considered that the best broken stone was that which was broken by hand. Hand-broken stone is more uniform in size if the work is well done, but the cost is so great that this method is now seldom used, crushers being employed instead. Stone ballast is most easily handled with forks, which have the additional advantage of screening out dirt and fine particles of stone.

Although broken stone is the best material for ballast, it should not on that account be used indiscriminately for light-traffic roads. Whether it should be used or not depends to a great extent on its price as compared with that of other good materials available. For many light-traffic roads, broken-stone ballast is an unjustifiable luxury.

4. Gravel.—Some grades of gravel are almost as good for ballast as broken stone. Gravel is the most common material used for ballast, since nearly every railroad has a bank at some point along the line where gravel can be dug out, perhaps with a steam shovel, loaded on flat cars or special ballast cars, and then hauled at a total cost of but a few cents per cubic yard.

5. Cinders.—Cinders have the advantages of affording good drainage, which is a very essential quality, and of being very cheap, since the use of cinders merely utilizes what is otherwise a waste product. A new railroad cannot avail itself of this cheapness, however, unless it operates with no ballast until enough cinders are produced to ballast the road, and this will, of course, take a long time. A great disadvantage of cinder ballast is that the cinders are rapidly reduced to dust, which in dry weather is blown about by the wind and causes much annoyance.

6. Slag.—In some localities where there are mills producing large quantities of slag, a railroad may obtain the slag without charge, the mill owners being glad to have it hauled

away. In its characteristics, slag is much like cinders, being dusty in dry weather, but affording fairly good drainage. Some kinds of slag contain chemicals that are injurious to the track, causing spikes and track bolts to rust with unusual rapidity, and attacking wooden ties and hastening their decay.

7. Shells, Culm, Etc.—Such materials as shells and culm are very cheap, but otherwise undesirable, and are used for ballast only under exceptional circumstances. They are very dusty in dry weather, and at all times are very imperfect in fulfilling the conditions of a good ballast material.

8. Mud-Ballast.—When no ballast is brought from other places, the natural soil is formed around the ties in a manner that fulfils to some degree, although imperfectly, the requirements of ballast. Only the most rigid demands for economy will justify this form of construction, except perhaps for very short stretches of the road, especially where the natural soil is of a gravelly character.

TIES

9. Railroad ties are usually made of wood. Their size and the kind of timber used depend on the locality and financial ability of the railroad company. The best ties are of white oak. The following list gives, in a descending scale, the comparative values of woods for cross-ties:

Hard Wood	Soft Wood
White oak	Red cedar
Rock oak	Black cypress
Bur oak	White cedar
Chestnut	White cypress
Southern pine	Tamarack
Walnut	Butternut
Cherry	White pine
Red beech	Hemlock
Red oak	Spruce

10. Choice of Wood.—Whenever it is possible to obtain ties in the immediate territory of the railroad line, it is

frequently more economical to employ them than to import ties from a considerable distance; but in deciding this question, the value of the various woods as well as their relative cost must be considered. It should be borne in mind that the true cost of ties in railroad work is the sum of many items besides that of the first cost. The labor of removing a worn-out tie from the track and replacing it with a new one is a very appreciable item, and its cost is practically the same whether the tie itself is a very cheap one or the most expensive that can be procured.

Cheap ties decay rapidly and must be often renewed; they do not maintain their alinement, and consequently require considerable work to keep the roadbed in condition. Whether, under given circumstances, it is better to use expensive ties with a long life or cheap ones is an important problem, as the kind of tie adopted affects the rail wear, the wear of rolling stock, and the speed of trains.

It should be observed that the supply of harder woods is becoming exhausted. The softer woods, either chemically treated or provided with tie-plates, to prevent excessive wear from the rail, are therefore beginning to come into more common use.

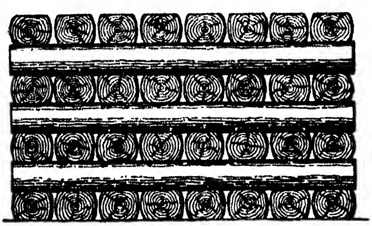


Fig. 1

11. Importance of Seasoning.—Too little attention is paid to the seasoning of ties before they are laid in the track. This is especially true on newly constructed lines, where scarcity of capital and the necessity for keeping down expenses compel the use of the cheapest material and methods. Ties thoroughly seasoned will last fully one-quarter longer than those used while green, and they are better in every way. Well-seasoned wood will hold the spikes better and resist the shearing tendency of the rails due to passing loads better than green ties. The most favorable months in northern latitudes for cutting ties are August, December, January, and February. During these months,

there is comparatively no movement in the sap of the trees. The ties should be hewn to uniform thickness and piled in square piles about $4\frac{1}{2}$ feet in height, as shown in Fig. 1, so as to allow the free circulation of the air and hasten the seasoning process.

12. Durability.—The durability of ties depends on many different causes. Ties on curves have a much shorter life than those on tangents, and the drainage of the ballast is a very important factor. Ties cut in the late fall or winter will last longer than those cut in the spring or summer. The amount of seasoning also has a great effect on the life of the tie. The weight and character of the traffic must also be taken into consideration.

One great cause of the failure of ties lies in the fact that the spikes will be partly pulled out by the action of the rail flanges. Redriving the spike in the same hole accomplishes little or nothing. Since the tie must be placed symmetrically under the two rails, the area in which spikes may be driven is limited to a very few square inches. When a spike must be withdrawn and driven in a new place, the available area is rapidly exhausted, and the tie is then said to be **spike-killed.** Many ties that are taken out because they are spike-killed are otherwise in good condition.

White oak decays very slowly. Pine, redwood, and cedar also resist decay well, but they are so soft that they are easily cut by the rail flanges and are also quickly spike-killed. This may, however, be largely prevented by the use of the tie-plates described in a subsequent article.

Oak ties are usually said to last 4 or 5 years, even on roads having the heaviest traffic; while with lighter traffic and good ballast, their life may run to 12 or 15 years, and even longer. The good qualities of oak are due chiefly to its hardness, which enables it to withstand the pressure of the rail and also to hold the spikes so firmly that they are not readily pulled out.

13. Kinds of Ties.—The best form of tie is that known as a **pole tie,** Fig. 2, which is made from single tree trunks,

the top and bottom being sawed or hewed to the proper dimensions. When larger trees are used for ties, they are necessarily sawed, and then they are usually made as **slab ties**, Fig. 3, two ties being made from each tree trunk; the line of division between the ties passes through the heart of the tree. From a still larger tree, **quarter ties**, Fig. 4, may be cut, four to a tree trunk.

It is generally accepted that hewn ties are superior to sawed ties. The surface of a well-hewn tie is a series of comparatively smooth surfaces. The effect of the ax is to close the pores as the chip is removed, which tends to exclude moisture.


FIG. 2

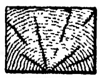


FIG. 3


FIG. 4

The effect of the saw is exactly the reverse: while giving a generally smoother surface, the saw tears the fiber of the wood, leaving the pores open. These minute broken fibers covering the entire surface of the tie act like sponges in attracting and retaining moisture, and eventually hasten decay. On trestle work, sawed ties are almost a necessity, since all the ties must have exactly the same thickness.

14. Specifications for and Inspection of Ties.—Specifications should include the dimensions and the kind and quality of timber. Ties for standard-gauge tracks should be from 8 to 9 feet in length, from 6 to 8 inches in thickness, and show not less than 6 inches of face. The **standard tie** is 8 feet 6 inches in length, 7 inches in thickness, and shows at least 7 inches of face.

Ties should be so nearly straight that a straight line passing from the center of one end to the center of the middle of the tie will not pass outside the tie at the other end. They should be cut off square and to uniform lengths, and be of uniform thickness throughout their entire lengths. Before being inspected, they should be delivered along the right of way of the railroad and piled in regular piles, each tie showing both ends. Ties are commonly graded as "firsts" and "seconds." The inspector carries a brush and pot of paint,

marking each class of ties with a distinctive mark. Firsts are usually marked with a full circle, and seconds with a cross.

15. Chemical Treatment of Ties.—The chemical preservation of timber is fully treated in *Foundations*, Part 1. In railroad work, chemical treatment is mainly applied to ties. Although trestles are sometimes constructed of chemically treated timber, it is preferable, when a permanent structure is desired, to use steel or masonry. If a treated tie costs twice as much as an untreated tie and lasts twice as long, it is more economical, since it saves the extra cost of placing the second untreated tie and the extra cost of maintenance of roadbed that is always involved when new ties are put in. On the other hand, it must be considered that to use the more expensive tie means the immediate investment of a larger sum of money with an added interest charge; but, as it has been found that the cost per tie when the number treated is large is never more than 25 cents, and is frequently as low as 8 or 9 cents, the large and growing cost of untreated ties makes the advantages of tie preservation even greater. A few years ago, the Chicago, Rock Island & Pacific Railroad published some statistics showing that the average life of a very large number of hemlock and tamarack ties that had been treated was found to be over 10½ years. Such ties, if untreated, would not have lasted one-half that time. Out of one lot of 21,850 ties, 12 per cent. still remained in the track after 15 years of service.

RAILS

16. History of Present Design.—Although the form of rail now almost exclusively used in the United States and in many other parts of the world is exceedingly simple, it was adopted only after many years of study and experimental work. Several years ago, the American Society of Civil Engineers appointed a committee to study the question. The committee entered into correspondence with the chief engineers of all important railroads in the United States,

and after much study a design was made, which has been adopted as standard by nearly all American railroads. Previous to the adoption of this standard, nearly every railroad of any importance had its own designs, which differed from those of other roads only in minor details, but the difference was sufficient to require the construction of a special set of rolls, thereby causing a considerable increase in the cost of the rails. The present standardization is not only an improvement but an economy.

17. Elements of the Design.—A rail must have a wearing surface sufficiently broad and tough to withstand, without excessive wear, the effect of rolling wheels carrying heavy loads. It must also have sufficient strength to act as a girder between the ties, and have a sufficiently broad base not to make the intensity of pressure transmitted to the tie greater than the crushing strength of the tie. Fig. 5 shows in cross-section the general form of the rail adopted by the American Society of Civil Engineers: PQ is the **head**; MN, the **web**; and KL, the **flange**, or **base**. The metal is distributed through the section in the following proportions: head, 42 per cent.; web, 21 per cent.; flange, 37 per cent. Instead of making the designs for different weights exactly similar figures, certain dimensions are maintained constant, while other dimensions are varied with the weight. The top of the head, instead of being flat, is a circular arc with a radius of 12 inches. The radius of the upper corner of the head is made $\frac{5}{16}$ inch; that of the lower corner of the head, $\frac{1}{16}$ inch. The four corners of the flange all have a radius of $\frac{1}{16}$ inch. The

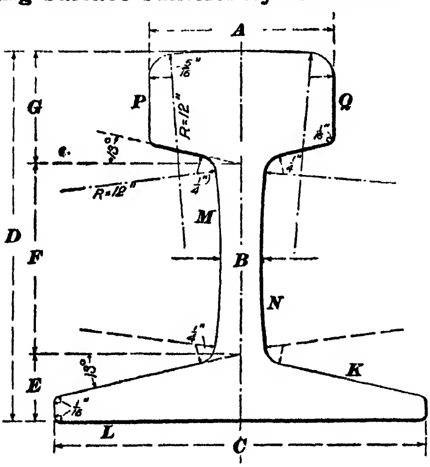


Fig. 5

TABLE I

WEIGHTS AND DIMENSIONS OF STANDARD RAILS

Rail Part	Weight per Yard, in Pounds												
	40	45	50	55	60	65	70	75	80	85	90	95	100
	Dimensions, in Inches												
A	$1\frac{7}{8}$	2	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{13}{32}$	$2\frac{7}{16}$	$2\frac{15}{32}$	$2\frac{1}{2}$	$2\frac{9}{16}$	$2\frac{5}{8}$	$2\frac{11}{16}$	$2\frac{3}{4}$
B	$\frac{25}{64}$	$\frac{27}{64}$	$\frac{7}{16}$	$\frac{15}{32}$	$\frac{31}{64}$	$\frac{1}{2}$	$\frac{33}{64}$	$\frac{17}{32}$	$\frac{35}{64}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{16}$
C and D	$3\frac{1}{2}$	$3\frac{11}{16}$	$3\frac{7}{8}$	$4\frac{1}{16}$	$4\frac{1}{4}$	$4\frac{7}{16}$	$4\frac{5}{8}$	$4\frac{13}{16}$	5	$5\frac{3}{16}$	$5\frac{3}{8}$	$5\frac{9}{16}$	$5\frac{3}{4}$
E	$\frac{5}{8}$	$\frac{21}{32}$	$\frac{11}{16}$	$\frac{23}{32}$	$\frac{49}{64}$	$\frac{25}{32}$	$\frac{13}{16}$	$\frac{27}{32}$	$\frac{7}{8}$	$\frac{57}{64}$	$\frac{59}{64}$	$\frac{15}{16}$	$\frac{31}{32}$
F	$1\frac{55}{64}$	$1\frac{31}{32}$	$2\frac{1}{16}$	$2\frac{11}{64}$	$2\frac{17}{64}$	$2\frac{3}{8}$	$2\frac{15}{32}$	$2\frac{35}{64}$	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{55}{64}$	$2\frac{63}{64}$	$3\frac{5}{64}$
G	$1\frac{1}{64}$	$1\frac{1}{16}$	$1\frac{1}{8}$	$1\frac{11}{64}$	$1\frac{7}{32}$	$1\frac{9}{32}$	$1\frac{11}{32}$	$1\frac{27}{64}$	$1\frac{1}{2}$	$1\frac{35}{64}$	$1\frac{19}{32}$	$1\frac{41}{64}$	$1\frac{45}{64}$

section of the web, instead of being made with two parallel sides, consists of two circular arcs having a radius of 12 inches each. These arcs are joined to the bottom of the head and the top of the flange by circular arcs having radii of $\frac{1}{4}$ inch. The straight lines at the bottom of the head and the top of the flange make an angle of 13° with the horizontal. The sides of the head are vertical lines. All these dimensions and angles are common to *all* weights of rails. The height *D* of a rail and the width *C* of its flange base are always equal to each other. The dimensions for the usual sizes, indicated by *A*, *B*, *C*, *D*, *E*, *F*, and *G* in the figure, are as given in Table I.

18. The chief discussion regarding the form of the rail centers on the question of the radius of the upper corner of the head. A rail with sharp corners will probably last longer, other things being equal, than one whose upper corner has a large radius; the sharp-cornered rail, however, will wear away the flanges of the car wheels more rapidly. The radius ($\frac{5}{16}$ inch) adopted for the standard rail is a compromise between the $\frac{1}{4}$ inch recommended by those who favor sharp corners, and the $\frac{1}{2}$ inch, or even $\frac{5}{8}$ inch, that has been used by some roads. It is found that, when the corner of the rail has been worn down so that it fits the flange of the wheel closely, the rail wears at a much faster rate than it did at first. The metal in the corner of the head has been termed "precious metal," and it certainly must be so regarded when rail wear is considered.

19. Required Weight of Rail.—One of the questions to be decided in constructing a railroad is the weight of rail that should be used. Unfortunately, there is no method by which this problem can be accurately solved. It is physically possible to run cars and locomotives over almost any weight of rail that is worth considering; but if the rail is too light, its deflection under heavy loads will increase the tractive effort required to haul the train, and therefore increase the amount of fuel and train supplies. A light rail will also increase the stresses on the rolling stock and the consequent

expenses for repairs, and will, besides, increase the danger of derailments, especially if the speed of the train is very great.

20. When a train stands on a track, the stresses in the rail depend on the weight borne by each wheel, on the distance between the ties, on the firmness with which the rail is spiked to the ties, and on the amount that the ballast and roadbed sink under the weight. The effect of these causes cannot be exactly calculated. When the train is in motion, the problem becomes still more complicated, especially at points of the track where the grade changes and on curves.

Since the exact stresses to which a rail may be subjected cannot be ascertained, it is impossible to compute theoretically the size or weight that the rail should have. It is, therefore, necessary to make use of practical rules that have been found by experience to give approximately satisfactory results. Two of these rules are here given:

Rule.—*Divide the greatest load, in pounds, that will be supported by any wheel by 224; the quotient is the required weight of the rail in pounds per yard.*

Example.—A consolidation engine has a load of 106,000 pounds on the eight drivers. Required the weight of rail that should be selected.

Solution.—Since there are eight drivers, the greatest load supported by any one wheel is 106,000 ÷ 8 = 13,250 lb.; therefore, the required weight of rail is

13,250 ÷ 224 = 59.1 lb. per yd. Ans.

21. The rule in Art. **20**, which was first published by the Baldwin Locomotive Works, gives fairly approximate results for light loads; for very heavy loads, however, the weights obtained by it are too large. The following rule agrees more closely with present American practice:

Rule.—*The weight of the rail, in pounds per yard, should equal the total number of tons of 2,000 pounds on all the drivers of the heaviest locomotive.*

Example.—To solve by this rule the example given in Art. **20**.

Solution.—The total weight on the drivers is 106,000 lb., or 53 T. The required weight of rail is therefore 53 lb. per yd. It is probable that in this example a 60-lb. rail would be selected.

EXAMPLE FOR PRACTICE

The total weight of a locomotive is 112,000 pounds, which is supported by eight drivers. Find by each of the foregoing rules the weight of rail required.

Ans. { By the rule in Art. **20**, 62.5 lb. per yd.
By the rule in Art. **21**, 56 lb. per yd.

---

22. Required Length of Rails.—Nearly all the railroads of the United States are laid with rails varying in length from 27 to 33 feet. It is believed by many engineers that longer rails would be better, because an increase in the length of the rail would decrease the number of rail joints and therefore lessen somewhat the cost, as well as the wear on the rolling stock. The decrease in cost resulting from the fewer rail joints is, however, partly counterbalanced by the extra expense of handling unusual lengths. As a 33-foot rail is about as long as the standard gondola or flat car, it can be transported more cheaply than a longer rail. Some railroads, however, have a considerable mileage laid with 60-foot rails.

23. Chemical Composition.—A difference of a few hundredths of 1 per cent. in the amount of carbon, phosphorus, or silicon in the steel makes a great difference in the properties of a rail. The amount of carbon usually varies from about .25 to .5 per cent., although standard specifications do not allow so wide a range. The amount of phosphorous should not be more than .1 per cent., and that of silicon not more than .2 per cent.; while manganese may vary in amount from about .7 to 1.5 per cent. Many other chemical elements are frequently found in very small quantities; among them is sulphur, which is considered very injurious. A small proportion of nickel will produce the famous **nickel steel.**

24. Testing.—Considering that the cost of rails is the largest single item in the construction of a road, very careful and rigid tests are made of the quality of the steel employed. Chemical tests are constantly made of the

steel used in each "blow," the object being to find out the amount of carbon, phosphorus, silicon, and manganese it contains. Rails are also tested mechanically, which is usually done by means of the "drop test." A piece of rail is placed head upwards on solid supports about 3 feet apart, and a drop hammer weighing 2,000 pounds is allowed to fall on the rail from a height varying from 15 to 19 feet, according to the size of the rail. If any rail is broken when thus struck, other tests are made of rails from the same "blow" of steel. If these fail, all the rails from that blow are rejected.

RAIL FASTENINGS

25. Rail Joints.—Any device for holding together the ends of two rails is called a **rail joint.** A rail joint should be sufficiently strong and stiff to preserve the exact alinement, both laterally and vertically, of the two rails. The only absolutely perfect rail joint is one in which the ends of the rails are welded together, but this is usually impossible on account of the necessity of allowing for the slight expansion and contraction caused in the rail by changes of temperature. An approach to a perfect joint is, however, obtained by some of the more recent designs. The old-fashioned fish-plate joints have been definitely abandoned in favor of the common angle-plate joint, to be described presently; and even the latter form, although the most commonly used, is being gradually replaced by forms that have still greater strength.

Considerable ingenuity has been exercised in trying to avoid the gap at rail joints, even though this gap is only $\frac{1}{4}$ inch. It has been thought that a large part of the jar that ordinarily occurs at a rail joint is due to this gap. It has, however, been demonstrated that the jar is very largely due to other causes; hence, the practice of cutting rails with a bevel joint of 45°, or any other form that produces an over-lapping joint, is found to be nearly useless, and the expense unjustifiable.

26. Angle Bars.—In Fig. 6 is shown the standard **angle bar or angle-splice joint.** The upper part of the

figure shows a section of the rail *AB* and the two angle bars *CDFE*; *HK* is one of the bolts passing through both angle bars (each of which is about ¾ inch thick) and the web of the rail. The nut *N* is tightened to hold the bars firmly against the flange and head of the rail, and is prevented from being shaken loose by the nut-lock *LM*, which is described in a subsequent article. The lower part of Fig. 6 shows a side view of one of the angle bars. It will be noticed that the six bolt holes *m* are slightly elongated;

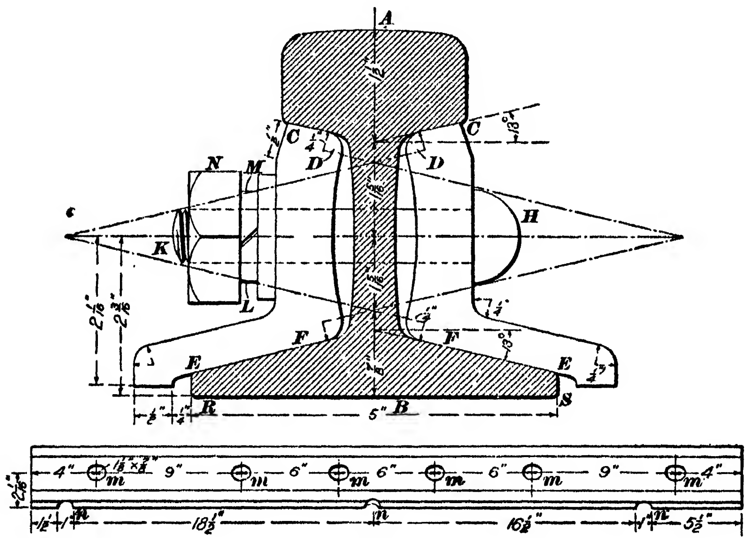


FIG. 6

this is to allow a slight play of the bolts when the rail expands or contracts in length, owing to changes in temperature.

However the details of angle bars may vary, they all have several important features in common. The upper surfaces *CD* should fit exactly against the lower surface of the head of the rail; and the lower surfaces *EF* should fit exactly on the upper surface of the flange. If the upper and lower surfaces make the required angle (13°) with the horizontal, the angle bar will act like a wedge and can be securely forced into place. The two angle bars, by being bolted together, will mutually stiffen each other and support the

rail. The broad base of the angle bars furnishes a large resisting moment against any tendency of the rail to bend laterally at the joint.

27. Other Forms of Rail Joints.—Many of the later forms of rail joints extend under the bottom of the flange RS, Fig. 6, and thus furnish a support for the base of the rail. The object of this is to prevent the end of one rail from sinking below the end of the other rail while the wheel load is running over them, and so battering the end of the rail and producing a serious shock. This feature is found in the Fisher bridge joint, the continuous rail joint, the Weber rail joint, and in some others. Other designs ignore this principle and consider that the only necessary modification of the angle plate is to bend down the metal so as to form a deep and

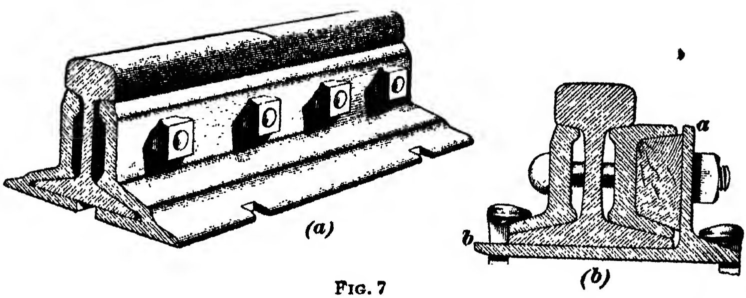


Fig. 7

nearly vertical web of metal that will furnish considerable extra resistance to bending immediately underneath the joint. Fig. 7 shows two patented forms of angle bars. In form (a), known as the **continuous rail joint**, the stiffness of the joint is increased by extending the lower edges of the angle bars under the flange of the rail. This also keeps the ends of the rails in exact adjustment vertically. In form (b), known as the **Weber rail joint**, the same result is obtained by adding an L-shaped plate $a\,b$, on which the whole rail rests. These two designs are probably the most prominent of recent patented forms, and have been very extensively adopted.

28. Tie-Plates.—A **tie-plate** is a plate of metal, sometimes provided with corrugations or teeth, which is placed on

the tie underneath the rail so as to distribute the pressure of the rail on the tie and prevent rail cutting. Fig. 8 shows two forms of tie-plates. These are placed lengthwise on the tie, so that the rail crosses them along the line *a b*. The square holes are for the spikes to pass through, two being driven on the outer side of the rail flange and one on the inner.

Ties made of soft wood require tie-plates much more than do hardwood ties. A cedar or redwood tie, though very durable with respect to decay, is so soft that it will be badly cut by the rail. When tie-plates are used, the life of the tie is largely increased.

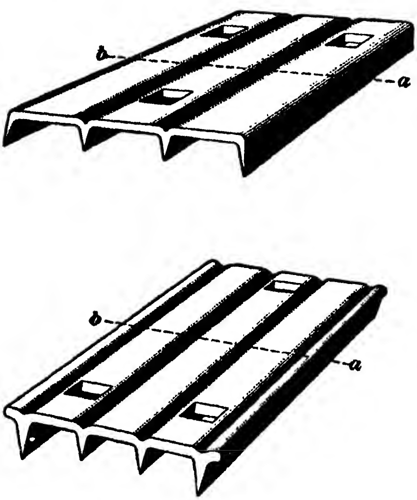


FIG. 8

29. The process of setting and spacing the tie-plates requires much care, since the location of the plates on the tie determines very closely the position of the rail, and, therefore, the gauge. As the best designs of tie-plates are provided with some form of teeth or corrugations, the two tie-plates should be placed on the tie, and spaced very accurately by means of a suitable gauge; and the teeth or corrugations should then be forced into the wood until both plates are firmly fixed on the tie. Ordinarily, tie-plates are pounded into place with a heavy sledge or a wooden maul.

30. Rail Braces.—The chief use of **rail braces,** two forms of which are shown in Fig. 9, is to resist the tendency of the rail to turn over. On this account, they are required on the outside of the outer rail on sharp curves, and on the outside of the inner rail when trains are likely to stop on the curve. The use of tie-plates avoids to a great extent the necessity for the use of rail braces; but, where tie-plates

are not used, the ties on sharp curves are cut very badly unless they are provided with rail braces. These braces are frequently made of cast iron, but the best forms are of

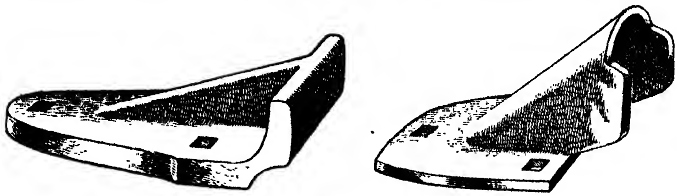


FIG. 9

malleable iron or else are stamped and punched from wrought iron by special machines.

31. Spikes.—The exact shape that a spike should have in order that its holding power may be as great as possible is still a matter of discussion. Two common and very good forms of spikes are shown in Figs. 10 and 11. It has been thought that, by nicking the corners of spikes, thus making them rough, their holding power would be increased, but experiments prove that this causes them to tear the fibers of the wood and thus lose much of their gripping strength. The best design is one that sharpens the point of the spike and gives it cutting edges and a wedge-shaped point. The fibers of the wood are then cut cleanly and forced backwards and downwards as the spike enters the wood. Then, when the spike manifests any tendency to displacement, the fibers of the wood will tend to return to their former positions and press the spike firmly from every side; hence, a plain spike with smooth edges is better than one with rough sides.

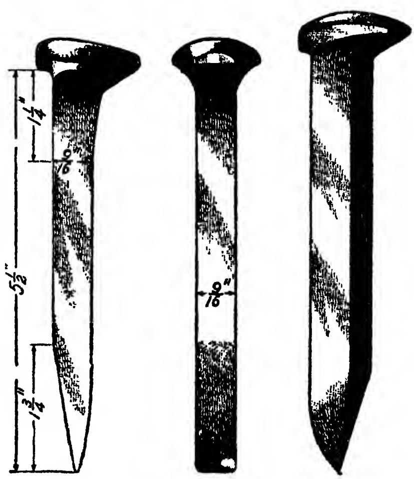


FIG. 10 FIG. 11

32. Track Bolts.—An inspection of rail joints will show that, to perform their duty properly, they are absolutely dependent on the strength of the **track bolts.** Owing to uncertainties in the stresses to which these bolts are subject, their proper size cannot be accurately computed. Practice, however, has demonstrated that a bolt with a diameter of $\frac{3}{4}$ to $\frac{7}{8}$ inch is sufficient for ordinary work, while, for the heaviest sections of rails, 1-inch bolts are desirable. The total length underneath the head of the bolt must be at least equal to the total distance between the two outer faces of the splice bars or angle plates plus the thickness of the nut-lock, if any is used, plus the thickness of the nut. On the other hand, the bolt should not extend more than $\frac{1}{2}$ inch outside of the nut when it is screwed up. These requirements make the length of the bolt vary from $3\frac{1}{4}$ inches, for light rails, up to 5 inches for 100-pound rails. For about $\frac{1}{2}$ inch in length immediately under the head of the bolt, the cross-section is given an elongated or elliptic form, which prevents the bolt from turning when it is screwed up. A standard design for a track bolt is shown in Fig. 12.

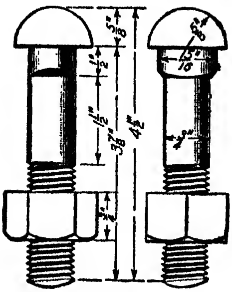


FIG. 12

33. Nut-Locks.—The excessive vibration to which rails are subjected during the passage of trains tends to loosen the nuts on the track bolts, and therefore some form of **nut-lock** is essential. The most common form, illustrated in Fig. 13, may be described as a ring that has been cut on one side and twisted into a spiral form, the ends of the spiral having rather sharp points. Such a ring is placed around the bolt, and the nut is screwed on. As the nut is screwed up, it flattens the ring and causes its two points to press on the under part of the nut on the one side and on the face of the angle plate on the other. In turning up the bolt, the nut slides easily past the point. Whenever there is any tendency for the nut to turn backwards,

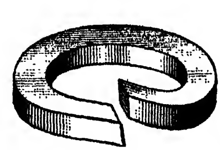


FIG. 13

the point of the steel spring bites into the nut and effectively prevents it from turning. A nut-lock is shown in position at *L M*, Fig. 6.

Many other forms of nut-locks are on the market, but their lack of simplicity makes them inconvenient, and they are comparatively little used.

COST AND REQUIRED QUANTITIES OF MATERIALS

34. Ballast.—It should not be forgotten that the actual cost of any system of ballast is not measured solely by the cost per cubic yard of the material delivered at the place where it is to be used. Some forms of cheap material will not only require extra work from the track gang all the time the ballast is being used, but will also add a considerable although an indefinite amount to the operating expenses, in the form of increased fuel and repairs. The real cost of the cheaper forms of ballast is far higher than their cost per cubic yard would indicate. Disregarding the uncertain elements just mentioned, it may be said that the expense of ballasting track depends on: (1) the first cost of the material as it comes to the road; (2) the distance that the material must be hauled; and (3) the method of handling. The first cost of some forms of ballast, such as cinders and slag, is sometimes practically nothing. In the case of gravel, the ballast may entail an expenditure comprising only the price (if any) of the gravel pit and the expense of excavating the material. The cost of loading gravel on cars with a steam shovel, provided that the shovel is economically operated, may run from 6 to 10 cents per cubic yard. The gravel may be placed and tamped for from 20 to 24 cents per cubic yard. The cost of gravel trains varies considerably, and is often made needlessly high, since such trains are invariably required to keep out of the way of all other trains; this causes the train crew and the gang of laborers, which must necessarily be large and correspondingly costly, to waste many hours waiting on sidings for regular trains to pass. The total cost of gravel ballast in the track is frequently

estimated at 60 cents per cubic yard; while that of broken stone in place will usually run from $1 to $1.25 a cubic yard.

35. Ties.—First-class oak ties cost about 75 to 80 cents, and even as much as $1 each. Chestnut ties can frequently be purchased at 50 or 60 cents. Where the railroad runs through country in which labor and suitable timber are cheap, ties may sometimes be bought and delivered on the right of way for as low a price as 20 cents each. Such a price, however, must be considered exceptional. A railroad often endeavors to control the supply of ties within its own territory, and to accomplish this end it discourages, by excessive freight charges, all attempts to ship ties out of the territory,

TABLE II

NUMBER OF TIES PER MILE

Distance From Center to Center Feet	Number of Ties	Distance From Center to Center Feet	Number of Ties
$1\frac{1}{2}$	3,520	$2\frac{1}{2}$	2,113
$1\frac{3}{4}$	3,017	$2\frac{3}{4}$	1,921
2	2,640	3	1,761
$2\frac{1}{4}$	2,348		

at the same time reducing as much as possible the prices that it will pay for them.

From Table II, the number of ties per mile of track can be obtained when the distance apart of the ties on the roadbed has been decided on.

36. Rails.—Steel rails are sold by the ton of 2,240 pounds. The market price constantly fluctuates; it has been as low as $22, and may range from $24 to $34 per ton. When the size of rail has been decided on, Table III will give the number of tons required per mile of single track. In practice, the numbers of this table should be increased 1 or 2 per cent. to allow for waste in cutting. The tons here referred to are 2,240-pound tons.

Example.—A track is laid with 30-pound rails. To find the cost for rails per mile of track if the price is \$26 per ton, allowing 2 per cent. for waste.

Solution.—From Table III the weight per mile is 47 T. + 320 lb. = 47.143 T. The cost is, therefore, 47.143 × \$26 = \$1,225.72. If 2 per cent. is allowed for waste, the total cost will be

\$1,225.72 × 1.02 = \$1,250.23. Ans.

TABLE III

WEIGHT OF RAILS REQUIRED PER MILE OF TRACK

Weight of Rail per Yard	Weight of Track per Mile		Weight of Rail per Yard	Weight of Track per Mile	
Pounds	Tons	Pounds	Pounds	Tons	Pounds
30	47	320	70	110	
35	55		75	117	1,920
40	62	1,920	80	125	1,600
45	70	1,600	85	133	1,280
50	78	1,280	90	141	960
55	86	960	95	149	640
60	94	640	100	157	320
65	102	320			

EXAMPLE FOR PRACTICE

A track is laid with 65-pound rails. If 1 per cent. is allowed for waste, and the price is \$30 per ton, what is the price of the track per mile? Ans. \$3,095.45

---

37. Angle Bars and Track Bolts.—Angle bars and track bolts are usually sold by the pound, except the patented forms of rail joints, which are sold by the pair. Table IV gives the number of pairs of angle bars per mile of track and the number of bolts for different rail lengths. The weight of a pair of angle bars varies widely with the pattern chosen. The form shown in Fig. 6 for 60- to 70-pound rail will weigh about 70 pounds per pair.

The average number of bolts of different sizes in each keg of 200 pounds is given in Table V.

The number and total weight of the angle bars and of the track bolts per mile of single track can readily be found by the use of Tables IV and V, when the pattern of angle bar and size of bolts have been selected.

TABLE IV

NUMBER OF RAILS, PAIRS OF ANGLE BARS, AND BOLTS PER MILE OF TRACK

Length of Rail Feet	Number of Rails per Mile	Number of Pairs of Angle Bars	Number of Bolts, Four to Each Joint	Number of Bolts, Six to Each Joint
18	587	587	2,336	3,504
20	528	528	2,112	3,168
21	503	503	2,012	3,018
22	480	480	1,920	2,880
24	440	440	1,760	2,640
25	422	422	1,688	2,532
26	406	406	1,624	2,436
27	391	391	1,564	2,346
28	377	377	1,508	2,262
30	352	352	1,408	2,112
33	320	320	1,280	1,920

TABLE V

NUMBER OF TRACK BOLTS IN A KEG OF 200 POUNDS

Bolts Inches	Size of Nuts Inches	Bolts in Keg	Bolts Inches	Size of Nuts Inches	Bolts in Keg
$\frac{3}{4} \times 4\frac{1}{2}$	$1\frac{1}{2}$ square	195	$\frac{1}{2} \times 2\frac{1}{2}$	1 square	654
$\frac{3}{4} \times 4$	$1\frac{1}{2}$ square	200	$\frac{7}{8} \times 3\frac{1}{2}$	$1\frac{3}{4}$ hexagonal	170
$\frac{3}{4} \times 3\frac{3}{4}$	$1\frac{1}{2}$ square	208	$\frac{3}{4} \times 3\frac{3}{4}$	$1\frac{3}{8}$ hexagonal	237
$\frac{3}{4} \times 3\frac{1}{2}$	$1\frac{1}{2}$ square	216	$\frac{3}{4} \times 3\frac{1}{2}$	$1\frac{1}{2}$ hexagonal	228
$\frac{5}{8} \times 4$	$1\frac{1}{4}$ square	305	$\frac{3}{4} \times 4$	$1\frac{3}{8}$ hexagonal	220
$\frac{5}{8} \times 3\frac{1}{2}$	$1\frac{1}{4}$ square	329	$\frac{5}{8} \times 3\frac{1}{2}$	1 hexagonal	415
$\frac{1}{2} \times 3\frac{1}{2}$	1 square	576			

EXAMPLE.—Suppose the angle bar shown in Fig. 6 is selected. The weight is 70 pounds per pair, and six $\frac{3}{4}'' \times 4''$ bolts are used. The length of rail is 30 feet; the price of the angle bars is 1.4 cents per pound, and of the bolts $5 per keg. What is the cost for angle bars and bolts per mile of track?

SOLUTION.—Since the rail is 30 ft. long, the number of pairs of angle bars is found from Table IV to be 352; the number of bolts (Table IV) is 2,112; the weight of the angle bars is $352 \times 70 = 24{,}640$ lb.; the cost of the angle bars is $24{,}640 \times \$.014 = \$344.96$. Ans.

TABLE VI

RAILROAD SPIKES PER MILE OF TRACK

Rails Used Pounds per Yard	Size Measured Under Head Inches	Average Number per Keg of 200 Pounds	Ties 2 Feet Between Centers Four Spikes to a Tie	
			Pounds	Kegs
45 to 70	$5\frac{1}{2} \times \frac{9}{16}$	375	5,870	$29\frac{1}{3}$
40 to 56	$5 \times \frac{9}{16}$	400	5,170	26
35 to 40	$5 \times \frac{1}{2}$	450	4,660	$23\frac{1}{3}$
28 to 35	$4\frac{1}{2} \times \frac{1}{2}$	530	3,960	20
24 to 35	$4 \times \frac{1}{2}$	600	3,520	$17\frac{2}{3}$
20 to 30	$4\frac{1}{2} \times \frac{7}{16}$	680	3,110	$15\frac{1}{2}$
	$4 \times \frac{7}{16}$	720	2,910	$14\frac{3}{4}$
16 to 25	$3\frac{1}{2} \times \frac{7}{16}$	900	2,350	11
	$4 \times \frac{3}{8}$	1,000	2,090	$10\frac{1}{2}$
16 to 20	$3\frac{1}{2} \times \frac{3}{8}$	1,190	1,780	9
	$3 \times \frac{3}{8}$	1,240	1,710	$8\frac{1}{2}$
12 to 16	$2\frac{1}{2} \times \frac{3}{8}$	1,342	1,575	$7\frac{7}{8}$

From Table V, the number of bolts to a keg is 200; the number of kegs is therefore $2{,}112 \div 200 = 10.56$; and the cost is $10.56 \times \$5 = \$52.80$. Ans.

EXAMPLE FOR PRACTICE

Solve the example in Art. **37**, if the angle bars weigh 50 pounds per pair, the rails are 25 feet long, and the bolts are $\frac{3}{4}$ in. $\times$ $3\frac{1}{2}$ in.

Ans. Angle bars, $295.40; Bolts, $58.61

38. Spikes.—Table VI gives the sizes of spikes commonly employed with the different rails, the average number of these spikes per keg, and the number of pounds of spikes required per mile of track, if the ties are laid 2 feet apart between centers. The price of spikes is variable, usually lying between $1\frac{1}{2}$ and 2 cents per pound.

LAYING TRACK

LAYING THE BALLAST AND TIES

39. Distributing Ties.—Ties, when distributed along the roadbed by teams, are strung out in proper numbers, so that the labor of carrying them to their place in the track may be as light as possible. The largest of them are reserved for joint ties, the joints being located by measuring from the ends of the rails already in place in the track. By measuring with a 30-foot pole, the joints of rails may be accurately located, a small stake being driven to mark each joint. This practice admits of the placing of ties several rail lengths in advance of the rail, thus affording working room for a much larger force than could otherwise be handled.

40. Preparation of the Subgrade.—It is a rare thing to find a new roadbed in proper condition for tracklaying; the surface, as left by the contractors, is usually rough and uneven. If the best work is to be done, the roadbed should first be filled to the proper subgrade, and then graded both ways from the center line with a slope of 24 : 1 for rock ballast (Fig. 14), or even with so high a slope as 12 : 1 for gravel or slag ballast (Fig. 17). Some specifications require that the subgrade should be rolled with a heavy roller before the ballast is laid; this has the advantage of furnishing a compact surface into which water will not readily penetrate, but from which it will run off to the sides.

41. Laying the Ballast.—The ties are sometimes laid on subgrade, and the rails immediately laid on them, and

bolted up and spiked to the ties; then a light construction train carrying the ballast is rolled over the rails and the ballast is dropped down between the ties. By raising the track with bars, the ballast is readily forced under the ties and tamped around them. This method, although very cheap on account of the facility that it affords for hauling ballast, is sometimes ruinous to the rails, because the ties are imperfectly supported on the subsoil, and the rails may become badly bent by the weight of the ballast trains rolling over them. A far better plan, even if it is a little more expensive, is to have enough ballast (a layer 1 foot deep) laid on the subgrade by the use of carts, or even by a contractor's temporary track if the magnitude of the work justifies it. The ties can then be laid and the rails bolted up and spiked, when, if the ballast has been well graded on the upper surface, the rails will be so evenly supported that they can safely carry ballast trains drawing whatever ballast is required later to fill in between the ties.

42. Laying the Ties.—Center stakes marking the alinement are driven at intervals of 100 feet on tangents and 50 feet on curves, where the degree of curve does not exceed 12°. On curves exceeding 12°, stakes should be driven at intervals of 25 feet. A tack is driven in each stake, marking the center of the track. Grade stakes for surfacing ties should be placed at intervals of 16 feet. A straightedge placed on these stakes marks the grade for the intervening ties.

The placing of grade stakes so close together is contrary to common practice, but the increased labor for the engineer is more than compensated by the saving of the time ordinarily consumed in sighting in ties where grade stakes are set at intervals of 50 or 100 feet. The surface is sure to be better where the straightedge is brought into use, and the danger of kinking rails or bending them out of surface is obviated.

A tie line for lining the ends of the ties is spaced at the proper distance from the center line and stretched taut, being fastened at suitable intervals by well-driven stakes. Joints

should not be located at any considerable distance in advance of the rails, as the measurements are likely to vary a little and soon accumulate an error. These inaccuracies are obviated by checking the measurements frequently from the ends of the rails already in place in the track. Care must be taken to place the ties at right angles to the center line; if laid askew, they prevent proper gauging of the track. Ties should be assorted with reference to thickness, in order that those of uniform thickness may come together in the track.

43. Spacing the Ties.—The distance of ties between centers varies from 18 inches to 3 feet. The requirements of tamping under the ties forbid their being placed closer together than about 18 inches between centers, and even then such a spacing can hardly be adopted unless the ties are small, since the clear space between the ties will be so narrow that good tamping will be impracticable. On the other hand, even with the largest ties that are ordinarily used, a greater spacing than 3 feet between centers will make too long a span for the rail. The more common spacing is 2 feet. However, ties are not usually spaced with perfect uniformity. Since the joint generally requires to be a little better supported, the ties under a rail are usually adjusted so that the spacing of the ties under the joints is a little closer than at other places.

44. The Roadbed.—If broken stone is used, the ballast is filled in even with the tops of the ties; it extends about

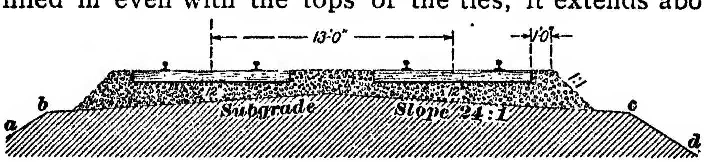


Fig. 14

1 foot outside of the ties, and then slopes down to the subgrade with a slope of about 1 : 1. The placing of the ballast outside of the ties in this manner secures the track against the tendency to lateral motion. The depth of ballast under the ties in the center should be about 12 inches. Fig. 14 shows a section of roadbed ballasted in this way.

A somewhat less expensive construction is shown in Figs. 15 and 16. The depth of ballast in Fig. 16 is 10 inches below the tie, while that in Fig. 15 is only 8 inches. The shoulders of the subgrade at *B* and *E*, Fig. 15, are frequently rounded off to improve drainage. Evidently, the construction illustrated in Fig. 15 will require far less ballast

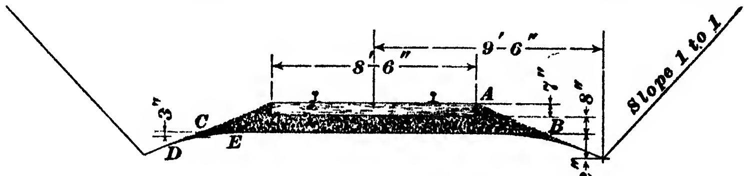


FIG. 15

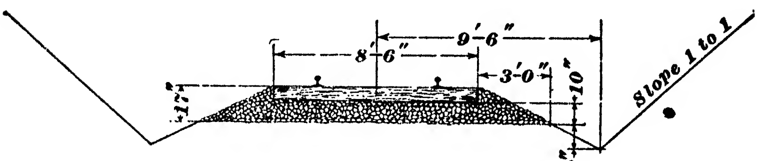


FIG. 16

and therefore be much less expensive than that shown in Fig. 14.

45. If the ballast is of cinders, gravel, or slag, the form of the cross-section should be as shown in Fig. 17. The depth under the center of the ties should be at least 12 inches.

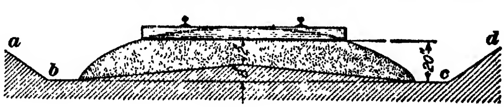


FIG. 17

The space between the ties is filled in with gravel, up to the top of the tie at the center, but it is sloped outwards so that the ends of the ties are not covered. This is done to avoid the rapid decay of the ends of the ties by accumulated water, as gravel ballast does not afford very good drainage.

46. The form of roadbed for mud-ballast is shown in Fig. 18. The chief object here is to secure as perfect drainage as possible. The soil is therefore raised to a height of about $2\frac{1}{2}$ inches above the ties at their middle point *A*, and

sloped toward the ends of the ties. The surface of the roadbed at the inside line *B* of the rails should be such as to permit the shovel to be passed freely underneath the rail between the ties. The slope is continued to the end of the tie, which it should just meet at its base line.

Outside of the ties, the shoulder *CD* should continue at a slope of 1½ inches to the foot to the edge of the embankment. This method insures complete drainage, as rain falling on the roadbed will run off before it can penetrate the ground. A comparison of this cross-section with that

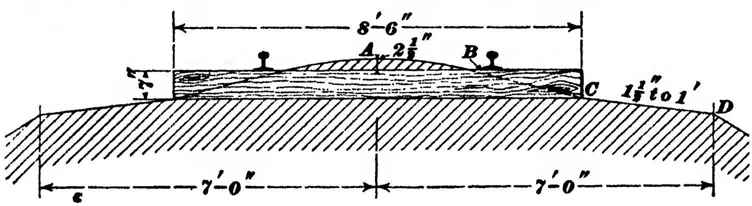


FIG. 18

for broken stone (Fig. 14) will at once show that mud-ballast has a much less secure hold on the tie, and is therefore unsuitable for supporting a track under conditions of fast speed and heavy traffic.

LAYING THE RAILS

47. Care in Unloading Steel.—Rails are often bent in consequence of careless handling. There is no excuse for

FIG. 19

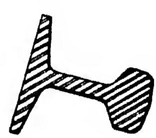


FIG. 20

either foremen or workmen allowing this to happen. Bent rails are unfit for laying until straightened; nevertheless, they are often laid in a bent state, giving a bad surface and line. The surest preventive is proper handling. The rails are always loaded properly at the rolling mill, and, if any kinks occur, they will be due to carelessness somewhere in transferring the rails or in delivering them on the grade. When it

is necessary to transfer rails, skids consisting of suitable rail lengths should be employed, along which the rails to be transferred are pushed or slid from one car to another. When, from scarcity of flat cars, rails are shipped in box cars, rollers are placed in the end doors of each box car, and the rails are rolled as they are transferred. The rails should always be placed in regular order, as shown in Fig. 19.

FIG. 21

In unloading, there should be men enough to handle the rails with ease and dispatch. The rail should be lifted clear of the car floor and carried to the edge of the car. All should be ready, and, at the word, the rail should be dropped

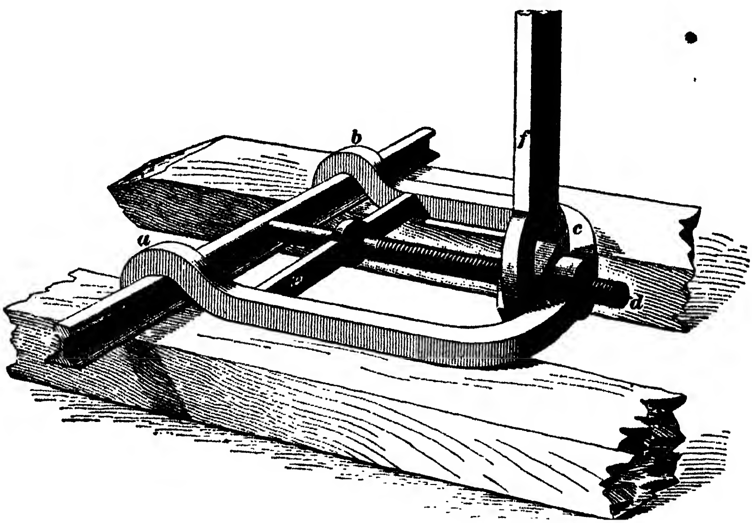


FIG. 22

clear of the car so that it will fall in the position shown in Fig. 20, in which position the danger of kinking is entirely avoided. Other men should stand on the ground to remove each rail as soon as it drops, so that one rail shall not fall on top of another. Rails should be dropped from the cars on dirt, and not on rock or loose stones.

48. Straightening Rails.—If, from any cause, rails are bent, they should be carefully straightened before being placed in the track. If **kinked,** that is, bent laterally, as shown in Fig. 21, they may be straightened by nicking the flange of the rail with a cold chisel on the convex side of the rail at the point *A* where the bend is sharpest. Then, laying the rail on its base, a few sharp blows with a sledge on the side of the head of the rail at the point *A* will remove the kink. Kinks may also be removed by means of a **rail bender,** or **jim crow,** shown in Fig. 22. The jim crow consists of two heavy hooks *a*, *b* that fit over the head of the rail; the curved bar *c*, which unites these hooks, is drilled at

FIG. 23

its crown, and threaded to receive the screw *d*. The cross-bar *e* unites with the two hooks *a* and *b*, and serves as a guide to the screw *d*. Force is applied to the screw by means of the wrench *f*, which has a long handle.

If the rails are surface bent, as shown at *A*, Fig. 23, they are most easily straightened with the jim crow. The straightening of the rails before laying will avail but little unless the surface of the roadbed is brought approximately to grade before trains are run over the track.

49. Gauging Track.—In tracklaying, no part of the work should receive more careful attention than the gauging

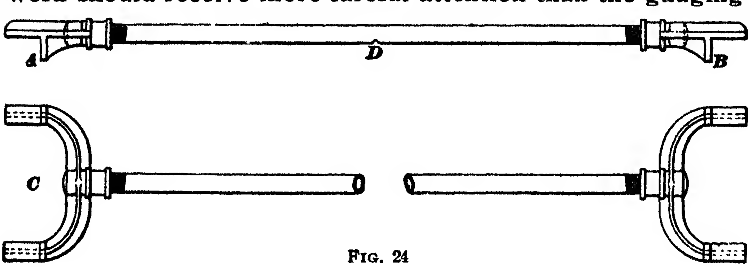


FIG. 24

of the track. A **track gauge,** to be in proper position, must be at right angles to the center line of the track, and with this fact in view the gauge shown in Fig. 24 was

devised. The gauge consists of two U-shaped castings, which are connected by a short iron pipe that is threaded at both ends and is screwed into them. The castings have lugs on their under sides, as shown at *A* and *B*; the distance *A B* between the lugs determines the gauge. A line drawn across the faces of the gauge lugs is at right angles to a line drawn through the center of the iron pipe. To place the gauge at right angles to the center line of the track, both lugs shown at *C* should be brought against the head of the rail. A notch filed in the gauge at *D* marks the center of the track.

50. Location of Rail Joints.—The rail joint may fall between two ties, in which case it is called a **suspended**

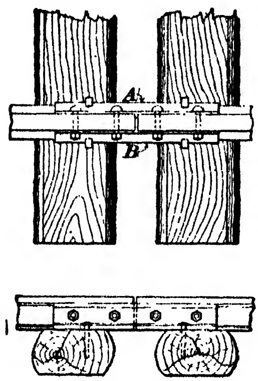


FIG. 25

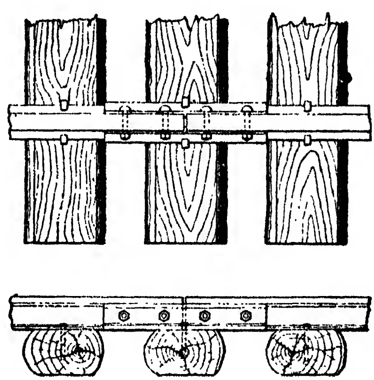


FIG. 26

joint, or it may be located above the center of a single tie, when it is called a **supported** joint. The suspended joint is now almost exclusively used on all roads in the United States. Fig. 25 shows a suspended joint, and Fig. 26 a supported joint.

In the suspended joint, there are two joint ties spaced about 6 inches in the clear. The joint is spaced midway between the ties, which should be carefully selected, have broad faces, and be of uniform thickness throughout.

In the supported joint, the tie is placed directly under the joint. It has been found that this construction gives a stiff,

unyielding joint that not only wears out more rapidly than the suspended joint but is also harder on the rolling stock.

51. Joints should always be so located that those along the inner line of the rail will each fall about midway between the joints on the outer line of the rail. Each joint is thus about opposite the center of the opposite rail. This insures smoother riding than if the joints in the two rails are placed opposite each other.

52. Spiking the Rails.—There is no part of tracklaying more likely to suffer from carelessness than the spiking. A spike, to be driven properly, should be started in a really vertical position. The spikes at the joints, centers, and quarters of the rail should be driven first. The right-hand rail is usually spiked first. The gauge is then placed on the fixed rail, and the free rail is brought to the gauge and spiked.

The common and slovenly custom of driving spikes at an angle should not be tolerated. An almost equally pernicious custom is to drive the spike with the track at loose gauge and then bend the head so as to give the rails their proper gauge.

53. The free rail should be carefully brought to the gauge. The inside spike should then be started a little removed from the base of the rail, and the head inclined slightly backwards. Having started the spike, a good blow will bring it to a vertical position, after which the blows should be delivered vertically on the head. The last blow should slightly draw the head toward the rail base. Where the gauge is widened on curves, a special gauge should be provided, and the eye should not be trusted to give the proper increase in gauge. Spikes should not be driven in the middle of the tie, especially in severe freezing weather, as they are liable to split it, but at a distance of from 2½ to 3 inches from the outside of the tie,

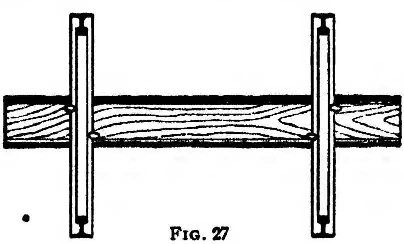


FIG. 27

where the wood is sure to be sound and the grain less open. The proper arrangement of the spikes in the tie is shown in Fig. 27.

54. Allowing for Expansion.—In laying track, provision must be made for the expansion and contraction of the rails, due to changes of temperature. As the temperature rises, the rail lengthens, and unless sufficient space is left between the ends to allow for the expansion, they abut one against another with such force as to cause the rails to kink or buckle, marring the appearance of track and rendering it unsafe for trains, especially those running at high speeds. If, on the other hand, too much space is left between the rails, the contraction or shortening of the rails due to severe cold may do equally great harm by shearing off the bolts from the splice bars, leaving the joints loose and unprotected.

55. To provide against the effects of expansion, an opening is left between the ends of the rails; and to provide

TABLE VII

SPACES BETWEEN ENDS OF RAILS

Temperature When Laying Track	Space to be Left Between Ends of Rails Inch	Temperature When Laying Track	Space to be Left Between Ends of Rails Inch
90° above zero	$\frac{1}{16}$	30° above zero	$\frac{1}{4}$
70° above zero	$\frac{1}{8}$	10° above zero	$\frac{5}{16}$
50° above zero	$\frac{3}{16}$	10° below zero	$\frac{3}{8}$

against contraction, the holes in both rail and splice bar are made oblong, allowing about $\frac{1}{4}$ inch for extreme movement. Table VII is a safe guide to tracklayers for most latitudes in the temperate zones. This table gives the spaces for a 30-foot rail. For a rail twice as long, or 60 feet, the spaces should be doubled; for a rail 15 feet long, spaces one-half as great as those given in the table will be sufficient; and similarly for any other length of rail. For an occasional short rail,

inserted in crossings or elsewhere, the spaces given in the table are frequently not modified.

56. To give to the track the proper opening at the joints, **expansion shims** are used. They are made of iron, and are of various forms. A simple and effective shim is made by bending a piece of $\frac{1}{8}$-inch iron into the form of a right angle, as shown in Fig. 28. This gives a combination shim of two thicknesses, namely, $\frac{1}{16}$ and $\frac{1}{8}$ inch. After the angle is formed, the $\frac{1}{16}$-inch shim is obtained by hammering the $\frac{1}{8}$-inch bar to the required thickness. The thickness of each shim should be clearly stamped on it. When put in place, the shim reaches the full depth of the head of the rail, and the bent portion lies flat on the top of the rail. The shims should not be removed until the joint is full bolted, and there should be a sufficient number on hand to keep the track-layers constantly employed, and avoid the delay incident to obliging them to wait until shims can be removed from bolted joints.

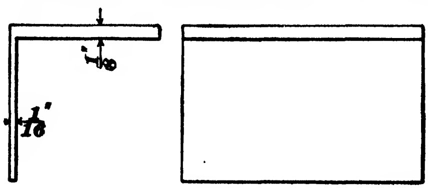


FIG. 28

CURVED TRACK

57. Difference in Length Between Inner and Outer Rails of a Curve.—It is evident that the radius of the outer rail of a curve is greater than that of the inner rail, and, consequently, its length is greater. This difference may be taken as $1\frac{1}{32}$ inches per degree of curve per 100 feet, for standard-gauge track. The difference in length between the inner and the outer rail of a curve may be found by either of the two following rules:

Rule I.—*Multiply the degree of the curve by the length in stations of 100 feet, and this product by $1\frac{1}{32}$; the result will be the difference in length between the inner and the outer rail, in inches.*

EXAMPLE.—The degree of a curve is 4°; the length, 520 feet. What is the difference in length between the inner and outer rails of the curve?

SOLUTION.— 520 ft. = 5.2 stations of 100 ft. each. $4 \times 5.2 = 20.8$. $1\frac{1}{32}$ in. = 1.03125 in. Then, the difference in length is $20.8 \times 1.03125 = 21.45$ in. = 1.7875 ft. Ans.

Rule II.—*Multiply the distance between the center lines of the rails by the length of the curve, in feet, and divide the product by the radius of the track curve; the quotient is the required difference in length, expressed in feet.*

EXAMPLE.—A 4° curve is 520 feet in length; the distance between the center lines of the rails is 4 feet $10\frac{1}{2}$ inches. What is the difference in length between the inner and outer rails of the curve?

SOLUTION.—The radius of a 4° curve is 1,432.69 ft.; 4 ft. $10\frac{1}{2}$ in. = 4.875 ft. The difference in length is, therefore, $\frac{4.875 \times 520}{1,432.69} = 1.77$ ft. Ans.

For light curves laid to exact gauge, the first rule is the simpler one, but for short curves where the gauge is widened, the second rule should be used. These rules should be applied in determining the number of short rails for curves, when loading material at the supply yard for forwarding to the tracklayers. A safe rule is to allow one $29\frac{1}{2}$-foot rail per 100 feet for each 6° of curvature. In laying track, the required number of short rails must be laid in proper order, otherwise the joints will not fall in their proper places. (Art. 50.)

EXAMPLES FOR PRACTICE

1. Find the difference in length between the inner and outer rails of a 10° curve 600 feet long, if the distance between the center lines of the rails is 4 feet 11 inches.

Ans. $\begin{cases} \text{By rule I, 5.156 ft.} \\ \text{By rule II, 5.142 ft.} \end{cases}$

2. Solve example 1 by rule I, if the curve is a 3° curve and 1,480 feet long. Ans. 3.816 ft.

58. Curving Rails.—In order that the line may be smooth, the rails on curves must conform to the curve of the center line. To accomplish this, the rails must be curved. The curving is done with a rail bender (see Fig. 22).

The **middle ordinate** of a curved rail is the distance *a a'*, Fig. 29, from the middle point of the chord joining the inner edges of the rail heads at the extremities of the rail

to the nearest point a' of the rail head. The similar distances $b\,b$ and $b'\,b'$, measured at points of the chord $A\,B$ one-fourth of the distance from B to A and A to B are called **quarter ordinates.**

TABLE VIII

MIDDLE ORDINATES, IN INCHES, FOR CURVING RAILS

Degree of Curve	Length of Rail, in Feet					
	30	28	26	24	22	20
1	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{8}$	$\frac{1}{8}$
2	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{3}{16}$
3	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{7}{16}$	$\frac{3}{8}$	$\frac{5}{16}$
4	$\frac{15}{16}$	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{7}{16}$
5	$1\frac{3}{16}$	$1\frac{1}{16}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{9}{16}$
6	$1\frac{7}{16}$	$1\frac{1}{4}$	$1\frac{1}{16}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$
7	$1\frac{5}{8}$	$1\frac{7}{16}$	$1\frac{1}{4}$	$1\frac{1}{16}$	$\frac{7}{8}$	$\frac{3}{4}$
8	$1\frac{7}{8}$	$1\frac{5}{8}$	$1\frac{7}{16}$	$1\frac{3}{16}$	1	$\frac{7}{8}$
9	$2\frac{1}{8}$	$1\frac{7}{8}$	$1\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{1}{8}$	$\frac{15}{16}$
10	$2\frac{3}{8}$	$2\frac{1}{16}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{16}$
11	$2\frac{5}{8}$	$2\frac{1}{4}$	$1\frac{15}{16}$	$1\frac{11}{16}$	$1\frac{3}{8}$	$1\frac{1}{8}$
12	$2\frac{13}{16}$	$2\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{13}{16}$	$1\frac{9}{16}$	$1\frac{1}{4}$
13	$3\frac{1}{16}$	$2\frac{11}{16}$	$2\frac{5}{16}$	$1\frac{15}{16}$	$1\frac{5}{8}$	$1\frac{3}{8}$
14	$3\frac{5}{16}$	$2\frac{7}{8}$	$2\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{3}{4}$	$1\frac{1}{2}$
15	$3\frac{9}{16}$	$3\frac{1}{16}$	$2\frac{11}{16}$	$2\frac{1}{4}$	$1\frac{15}{16}$	$1\frac{9}{16}$
16	$3\frac{3}{4}$	$3\frac{1}{4}$	$2\frac{13}{16}$	$2\frac{3}{8}$	$2\frac{1}{16}$	$1\frac{11}{16}$
17	4	$3\frac{1}{2}$	3	$2\frac{9}{16}$	$2\frac{3}{16}$	$1\frac{3}{4}$
18	$4\frac{3}{16}$	$3\frac{11}{16}$	$3\frac{3}{16}$	$2\frac{11}{16}$	$2\frac{5}{16}$	$1\frac{7}{8}$
19	$4\frac{7}{16}$	$3\frac{7}{8}$	$3\frac{3}{8}$	$2\frac{7}{8}$	$2\frac{7}{16}$	2
20	$4\frac{11}{16}$	$4\frac{1}{8}$	$3\frac{9}{16}$	3	$2\frac{9}{16}$	$2\frac{1}{8}$

The length of the middle ordinate may be computed by the formula

$$a\,a' = \frac{c^2}{8R} \qquad (1)$$

in which c = length of the rail $A\,B$;
R = radius of circular curve.

The quarter ordinate is always three-fourths of the middle ordinate; that is,

$$b\,b = b'\,b' = \tfrac{3}{4}\,a\,a' \qquad (2)$$

EXAMPLE.—To find the middle and quarter ordinates of a 30-foot rail for an 8° curve.

SOLUTION.—The radius of an 8° curve is 716.78 ft. Substituting in formula 1, we find

$$\text{middle ordinate} = \frac{30^2}{8 \times 716.78} = \frac{900}{15{,}734.24} = .157 \text{ ft.} = 1\tfrac{7}{8} \text{ in.} \quad \text{Ans.}$$

From formula 2,

$$\text{quarter ordinates} = \tfrac{3}{4} \times 1\tfrac{7}{8} \text{ in.} = 1\tfrac{13}{32} \text{ in., or, say } 1\tfrac{3}{8} \text{ in.} \quad \text{Ans.}$$

59. Table VIII gives the middle ordinates for different lengths of rails and degrees of curve. This table is not carried beyond the values corresponding to a length of 30 feet for $A\,B$, Fig. 29. For longer rails, and usually for shorter ones also, it is generally most convenient to curve a part

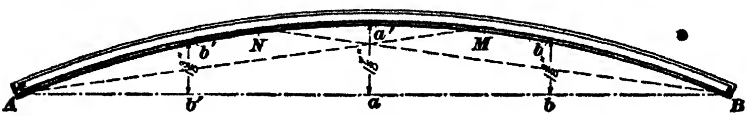


FIG. 29

of the rail at a time. Thus, if $A\,B$ were a 33-foot rail, a cord 20 feet long would be stretched from A to M, and the portion $A\,M$ curved, after which the cord would be stretched from B to N and the portion $B\,N$ curved. The middle ordinates for the 20-foot chords $A\,M$ and $B\,N$ can be taken from the table.

In curving rails, the ordinate is measured by stretching a cord from end to end of the rail against the gauge side, as shown in Fig. 29. To insure a uniform curve to the rails, the quarter ordinates at b and b' should be tested.

With practice, a man having a good eye and good judgment will soon find his eye measurements closely checking his table measurements. When a number of rails is to be curved for curves of different degrees, it is a good plan to mark the degree of the curve of each rail in white paint on the web of the rail on the concave side.

The use of sledges in curving rails should under no circumstances be allowed. There is great danger of fracture,

and often a flaw is caused that, while not perceptible at the time, may, under the stresses caused by frost and heavy trains at high speed, result in a broken rail, with serious consequences. Some of the worst accidents on record have been caused by broken rails, weakened by hard usage while being curved.

EXAMPLE FOR PRACTICE

By formulas **1** and **2** of Art. **58**, and also by Table VIII, find the middle and quarter ordinates to the following rails: (*a*) Rail length is 20 feet; degree of curve is 10°. (*b*) Rail length is 30 feet; degree of curve is 6°.

Ans. (*a*) By formulas: $a a'$ is 1.05 in.; $b b$ is .79 in.; By Table VIII: $a a'$ is $1\frac{1}{16}$ in.; $b b$ is $\frac{51}{64}$ in.; (*b*) By formulas: $a a'$ is 1.41 in.; $b b$ is 1.06 in.; By Table VIII: $a a'$ is $1\frac{7}{16}$ in.; $b b$ is $1\frac{5}{64}$ in.

60. Widening Gauge on Curves.—In passing over curved track, the car wheels bind hard against the outside rail at the curve. This is because the difference between the gauge of the track and that of the wheels is taken up by the wheel base, which forms a chord to the curve of the track, instead of being parallel to the rails, as is the case on a straight line. To lessen this friction, the gauge is usually widened on curves to the amount of $\frac{1}{16}$ inch per degree, but never to exceed 1 inch on any curve.

61. Putting the Elevation in Curves.—As explained in *The Transition Spiral*, the outer rail of a curved track

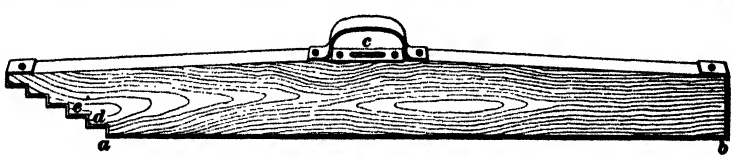


FIG. 30

must be superelevated. The elevation of the outer rail is determined by means of the **track level** shown in Fig. 30. For leveling track, the edge $a b$ of the track level is placed on the rails, and when the bubble c of the spirit level rests in the middle of the tube the rails are at the same height. The steps d, e, etc. of the track level are made 1 inch in

height, so that, when the step *d* is placed on the outer rail of a curve and the rail raised until the bubble of the spirit level rests in the middle of the tube, the outer rail has an elevation of 1 inch. Similarly, the step *e*, when brought to a level, would indicate a track elevation of 2 inches, etc.

Having determined the amount of elevation required for the curve, the outer rail is raised with the track jack and the ballast is thoroughly tamped under the ties. The elevation should be about ½ inch in excess of that required, in order that provision may be made for settlement.

In dressing the track after the elevation has been made, if mud or gravel ballast is employed, the crown of the ballast should not be more than one-third of the width of the gauge from the outer rail, in order to secure drainage. The raising of the outer rail reduces the outer slope and increases the inner slope of the ballast. If the curve is sharp, the ballast on the outer half of the track is practically level and holds water, instead of shedding it. By crowning the ballast as directed, thorough drainage is insured.

62. Guard-Rails.—When a guard-rail is inserted on a straight track, laid to exact gauge, it should be spaced 1⅞ inches from the gauge rail; but when the gauge is widened, as on sharp curves, the amount of the increase in gauge must be added to the space between the gauge and the guard-rail.

MAINTENANCE OF TRACK

63. Maintenance work includes keeping the track to grade, keeping the track in alinement, replacing worn-out material with new material, and the general care of track.

KEEPING THE TRACK TO GRADE

64. Shimming the Track.—All mud-ballasted track heaves greatly, and stone-ballasted track heaves to a less degree, from the action of frost. During the colder months of the year, all track should therefore be carefully watched, and at all times portions of the track in cuts or elsewhere, where the subgrade is likely to be poor, should receive attention. Where small inequalities are found, they should be corrected by shims placed beneath the rail. **Shims** are thin wedges, made of hardwood, which are driven crosswise under the rail. All shims over $\frac{1}{4}$ inch in thickness should have a hole bored in them to receive the spike. Shims are most easily made by boring a hole through the end of a straight-grained plank and cutting off a piece to the required length, after which the plank may be split into shims of the desired thickness. If the rail has cut into the tie, the edges of the groove must be adzed smooth before placing the shims, in order that the rails may have a solid bearing. If the track continues to heave, thin shims must be replaced by thicker ones. All high-shimmed track should be closely watched, and as the frost leaves the track and the track settles, thinner shims must be substituted for the thick ones. The last shim must not be removed until the frost has left the ground. When the shimmed rail is higher than the rest of the track by an amount equal to the thickness of the shim, it is known that the frost has left the track. All good shims, spikes, and braces should be stored in the tool house, to be in readiness when needed the following winter.

65. Removing Sags in the Track.—When a large sag occurs in the track, it will usually be necessary to insert additional ballast. The approximate amount of ballast required may be found by the following method: A stake is driven at *C*, Fig. 31, against the rail at the middle point of the sag, until its top is on a line with the track surface at *A* and *B*. The height *CD* of the stake above the rail is measured. The product of one-half the distance *AB* by the top width of the embankment and by the height *CD* of the stake above the rail is then divided by 27. The quotient is the number of cubic yards of material required.

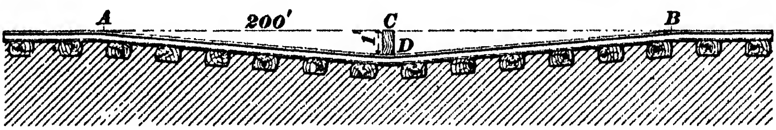


FIG. 31

EXAMPLE.— *AB* is 200 feet, *CD* is 1 foot, and the top of the embankment is 14 feet in width. How many cubic yards of material are necessary to take out the sag?

SOLUTION.—Number of cubic yards is

$$\frac{200}{2} \times 14 \times 1 \div 27 = 52, \text{ nearly. Ans.}$$

66. When the additional ballast, if any is required, has been piled between the rails at the sag, the track is raised as follows: A board 1 in. × 4 in. and 5 feet long is prepared, having two notches cut in it, each 3 inches deep, to fit over the rails, the space between the notches being equal to the gauge of the track. This **sighting board**, as it is called, is placed at a high point in the track, from eight to ten rail lengths ahead of the point where the track raising is to commence. The sighting board is shimmed up to a perfect level, and given the same height as that to which the top of the rail is to be raised. Then, at the point where the track raising is to commence, the track is lifted to the desired height, bringing both rails to the same level. The spirit level is then laid aside and the intervening track brought to a surface by sighting. When sighting, the foreman should stand from 50 to 75 feet from the track being raised. Each

rail should be raised and tamped about $\frac{1}{4}$ inch higher than the actual surface. In raising, two jacks, a heavy and a light one, should be used for each rail, the heavy one to raise the joints, and the light one to raise the centers of the rails. A rail center should not be raised until the jack is in place at the next joint; the two jacks are then raised together. This prevents the springing of the rails and insures a smooth surface.

By sighting in the rails, a more uniform surface is obtained and the delay occasioned by the repeated use of the spirit level is avoided. When the sighting board is reached, it is removed, and the track brought up to the proper surface by sighting.

In raising track, both sides should be lifted together. The common custom of raising and tamping one side of the track at a time should not be permitted, as in that way ties cannot be given a uniform bearing.

67. Curved Track.—As curved track offers greater resistance to riding and greater danger to passing trains than straight track, special effort and pains should be taken to maintain it in good order. All trackmen know that a low spot on a curve will cause every car in a train to lurch heavily toward the low side. It is highly important that the elevation of the outer rail should be kept uniform, but no foreman, however experienced, should depend on his eye alone in estimating curve elevation. The proper elevations must be given by the engineer, and the outer rail brought to grade as directed for laying new track.

KEEPING THE TRACK IN ALINEMENT

68. Lining Track.—After the track has been brought to grade, stakes should be set by the engineer along the center line, and the rails brought into alinement with the help of the track gauge (Art. **49**). Straight track may be pretty accurately lined without stakes as follows: The line side of the track is given a perfect line. Either rail may be

taken as the line side, but the same rail should always be used for lining. The foreman should stand with his back to the sun and as far from the piece of track that he is to line up as his eyesight will permit. This gives him a better view of the straight portions on each side of the crooked portion. A simple device, much practiced by trackmen when lining track, is to place small lumps of dirt on the top of the rail to be straightened. These lumps show plainly in contrast to the bright, unbroken surface of the rail, and when brought into range insure a good line.

69. In the case of a badly lined curve, the following directions for lining without an instrument are useful:

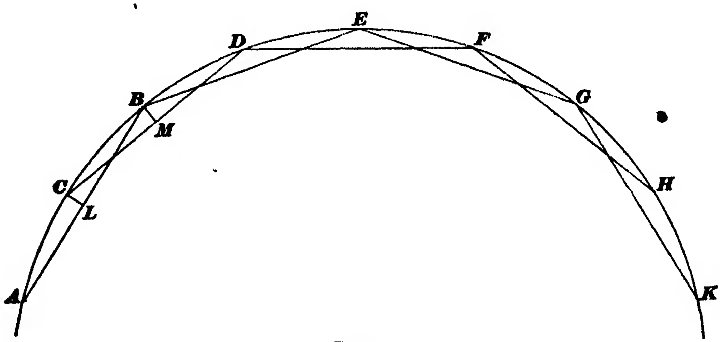


FIG. 32

Select a piece of track 60 feet in length, which appears to be in good line. There are few curves, however badly out of line, that will not show at least 60 feet of good line. At each end of the 60 feet of good track, set an accurate center stake, and one in the center of the track midway between them. In Fig. 32, A and B represent the center stakes 60 feet apart, and C the stake midway between them. Stretch a cord from A to B, and measure the distance from L, its middle point, to C. The distance CL is the middle ordinate of a 60-foot chord. Next, mark the middle point L of the cord, and move the end A of the cord to C. Measure from B the distance $BM = CL$, and carry the measuring cord forwards, stretching it taut, and in the line CM, as determined by the offset BM. The forward end D of the

cord will mark the spot for another track center. Then, move ahead as before, measuring another offset and stretching the cord to locate another center stake at *E*. In this way a good curve may be run in without the use of an instrument.

NEW MATERIALS

70. Estimating New Ties for Repairs.—The proper time for estimating the number of new ties needed for repairs is in the fall of the year. In northern latitudes, the winter is the proper season for manufacturing ties, and most tie contracts are let in that season. If the estimates are made up and sent in to the roadmaster in the fall, he can make more favorable contracts and be sure of having a supply when needed.

In making his estimate, the foreman should walk over his entire section, testing every tie of which he is in doubt and reporting the actual number needed, and no more. The renewing of ties is one of the great items of cost in the maintenance of a railroad, and a careful foreman can do much toward prolonging their life.

Minute regulations are usually provided to prevent ties from being prematurely taken out from the track. Some regulations attempt to specify how much of a blow an old tie should withstand from a track pick before it should be considered worthless. Estimates for ties should be based on actual count, and those to be renewed should be marked at the time the count is made.

71. Placing New Ties in Track.—When renewing ties, no more material should be removed from the track than is necessary to allow the new tie to go into its proper place. If two ties side by side need renewal, a single trench between them will serve for removing both. The spikes are drawn and the rail is sprung up from adjoining ties, a spike being slipped under it. The old tie is then knocked into the trench and pulled out. The new tie is pulled into the trench from the opposite side of the track, two men sliding it into

place and keeping it well up against the rail until it is in position. The tie must be held up against the rail with a bar while it is spiked, and the ballast thoroughly tamped with a tamping bar. All new ties must be placed square across the track, and if the old ones are too widely spaced, additional ties must be put in the track with selected ones at the joints. When all the rotten ties are removed from one rail length, the track should be filled in and dressed before another rail length is begun.

72. Inserting New Ballast.—When old track is to be newly ballasted with stone, gravel, or cinders, all dirt should be removed from between and from the ends of the ties down to their base, and placed on the shoulder of the roadbed. This will considerably strengthen the roadbed and afford a support to the ballast. If the whole road cannot be reballasted, the first ballasting should be done in the cuts, for it is here that drainage is most difficult.

GENERAL CARE OF TRACK

73. The care of track includes the removal of snow in winter, the mowing of weeds and grass along the right of way in summer or fall, the clearing out of side ditches, culverts, etc. after heavy rains, and a full and accurate knowledge of the condition of the road at all times. The right of way should never be allowed to fall into an appearance of neglect. Old ties should be neatly piled, ready to be disposed of or burned; iron links, old tie-plates, etc. should be carefully gathered up, and the whole section kept continually in as neat a condition as possible. A new man can make no better impression than by beginning, immediately after he takes charge, to attend carefully to these details.

TRACKWORK

(PART 2)

TURNOUTS

DEFINITIONS AND GENERAL DESCRIPTION

1. Definition.—A **turnout** is a contrivance for passing from one track to another. A turnout is sometimes called a *switch*, although, properly speaking, a switch is but one of the parts of a turnout.

In Fig. 1, MN represents the main line and WS a side track. To turn the train off from the main track on to the side track, part of the main rails must be bent to the left, as shown by the dotted lines BA', CD', until they meet the curved rails of the side track. A train running in the direction MN will then be turned to the left on reaching C, and pass over the turnout to the side track WS.

2. Parts of a Turnout.—The principal parts of a turnout are as follows:

1. The **switch**, which is the movable part of the turnout, and consists of two **switch rails** BA, CD, Figs. 1 and 2. The fixed ends B and C of the switch rails are called the **heels** of the switch; the movable ends A and D are called the **toes** of the switch. The distance AA' or DD' through which the toe moves is called the **throw** of the switch.

2. A **frog** K, Fig. 1, by means of which the flanges of the wheels moving along the rails $CD'Q$ can cross the rail EP.

3. Two **guard-rails** R, R', Fig. 1, one on each track, and both opposite the frog.

3. Train Facing or Trailing a Switch.—The cross-tie F, Fig. 2, that supports the toes of the switch is called the **head-block.** If a train is running in such a direction that it passes over the head-block before it reaches the frog, it is said to **face** the switch. If it is running in the opposite direction, so that it passes over the frog before it reaches the head-block, it is said to **trail** the switch. Thus, a train moving from M

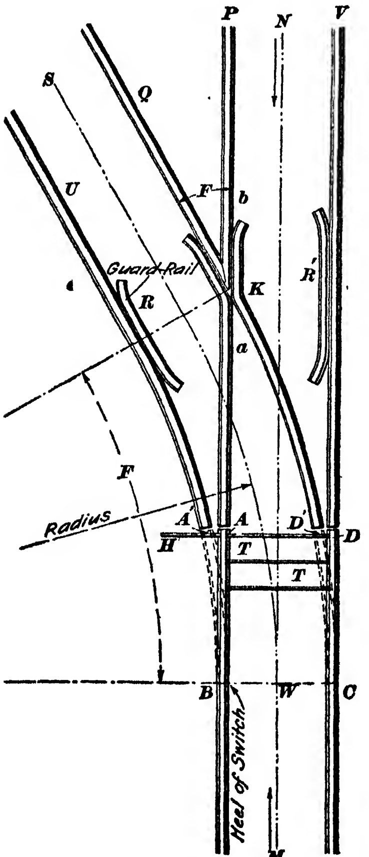


Fig. 1

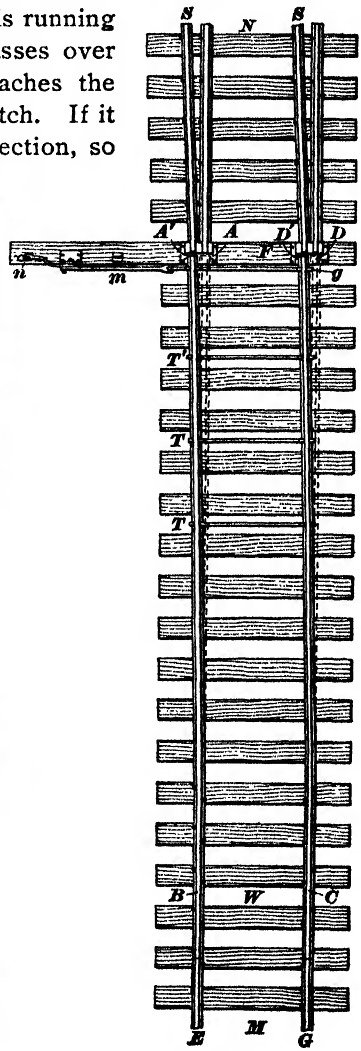


Fig. 2

to N is facing the switch, while one moving from N to M is trailing the switch.

4. Tie-Rods.—The main-line rails EB, GC, Figs. 1 and 2, are spiked firmly to the ties between B and E and between C and G. The ends BA and CD of these rails are not spiked, but are kept to the proper gauge by **tie-rods** TT'. The tie-rod at g, Fig. 2, is called the **head-rod**. It extends outside the rails, and through the **connection-rod** m is attached to the lever n of the switch stand, by means of which the switch rails are moved from their connection with the main-track rails at A and D to a connection with the turnout rails at A' and D'. The operation of thus moving the switch rails is termed **throwing the switch.**

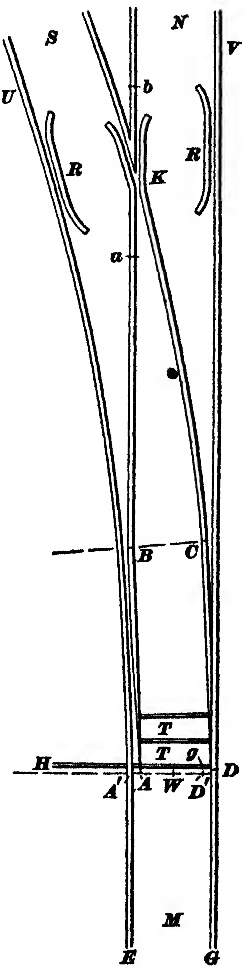


FIG. 3

SWITCHES

5. Kinds of Switches.—There are two kinds of switches, which differ in the arrangement and form of the switch rails; namely, the *stub switch* and the *point switch*. In the **stub switch**, Figs. 1 and 2, a part of each main-track rail is bent over to connect with the side track. In the **point switch**, Fig. 3, the outer rail GV of the main track is spiked rigidly to the ties; the opposite rail $EA'U$, lying partly in the main track and partly in the side track, is also firmly spiked: these two rails are immovable. The two switch rails BA and CD are planed to thin edges at A and D. The ends B and C of these rails are the fixed ends or heels; the thin edges

at A and D are the toes. The head-block is at H, and the head-rod at g.

When the point switch is set as shown in Fig. 3, a train moving in the direction MN will be turned to the left on passing D. If the switch is thrown so that the toe D is moved to D', and A is pressed firmly against the spiked rail at A', the train will remain on the main track MN.

It will be noticed that in the stub switch the head-block is between the heel and the frog, while in the point switch the heel is between the head-block and the frog.

6. Point of Switch.—The point of the center line at which the turnout begins is called the **point of switch.** In Figs. 1 and 3, W is the point of switch. In stub switches, the point of switch is midway between the heels; in point switches, it is midway between the toes and above the head-block.

7. Stub Switches.—The stub switch is now very little used except for the cheapest class of work. The first and most serious objection to it is that if it is misplaced the train will be derailed. From Fig. 1, it will be seen that a train on the main track moving in the direction NM will be derailed on reaching the open joint at A, if the switch is set for the side track. Similarly, when the switch is set for the main track, a train moving from S toward M will be derailed at A'. Another defect of the stub switch is the open joint at the head-block. In passing over this joint, each wheel strikes the ends of the rails a heavy blow, which not only batters the rails but also causes a heavy jolt to the car, injurious to the rolling stock and causing much discomfort to passengers. Stub switches are more liable to misplacement than point switches, and there is the constantly recurring need of recutting the ends of the rails at the head-block to provide for expansion and for the removal of battered ends. Another serious defect of stub switches is their want of stiffness. The looseness of the rails and the impractibility of adequately stiffening them make it impossible to operate the switches at high speed. They should never be used for turnouts from the main track; their use for a branch-off from

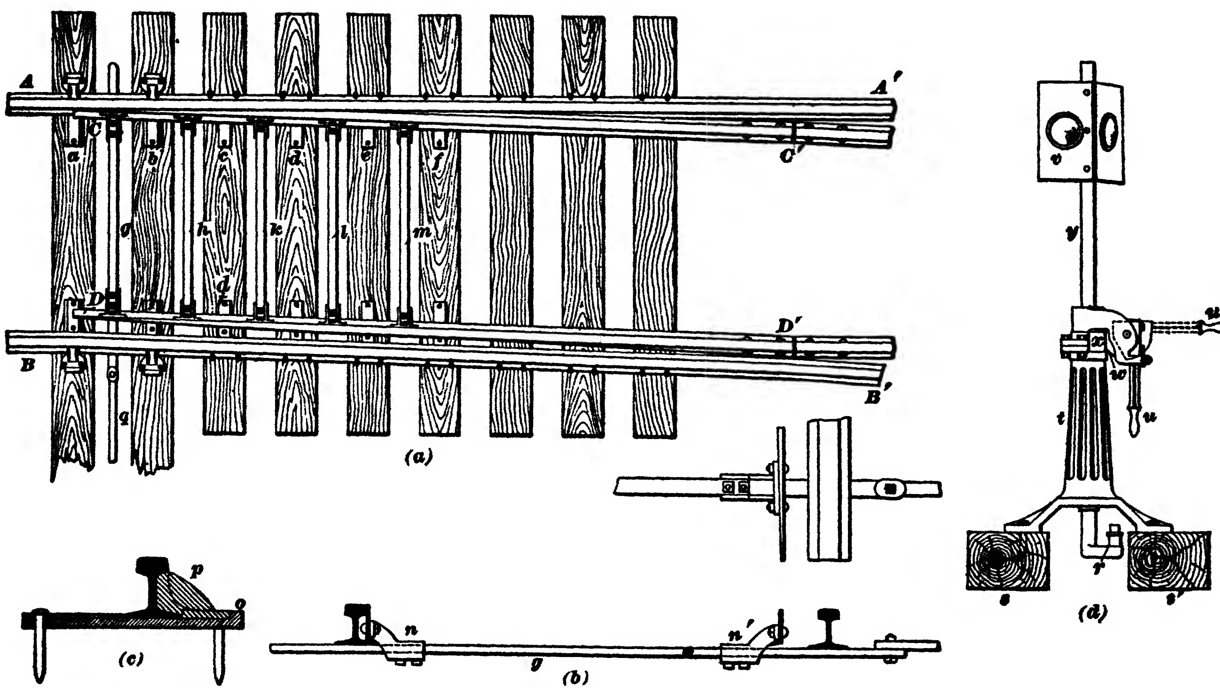


FIG. 4

a siding may be tolerated on account of their cheapness. In many states, the use of stub switches in main-line track is prohibited by law.

8. **Point Switches.**—The ordinary form of point switch is shown in Fig. 4. The switch rails are usually straight and planed down so as to fit closely to the spiked rails for 6 or 7 feet. The points *C* and *D* shown at (*a*) are planed down to a thin edge, the web of the switch rail being grooved so as to fit under the head of the spiked rail. The base of the switch rail is planed so that it fits snugly against the upper part of the base of the spiked rail, as shown in Fig. 5. The extreme points of the switch rails are slightly below the level of the spiked rails, so that the wheel treads *A B*, Fig. 5, do not come in contact with them until the size and strength of the switch rails are sufficient to stand the hard pounding that the switches receive.

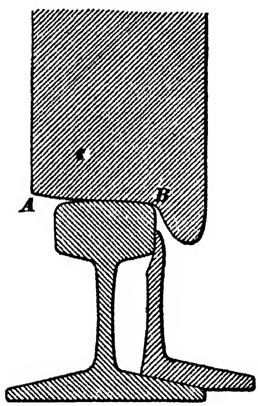


FIG. 5

The slide plates *a*, *b*, *c*, *d*, *e*, and *f*, Fig. 4, extend under the spiked rails and points, and are spiked to the cross-ties. The switch rods *g*, *h*, *k*, *l*, and *m* are of wrought iron, and of such dimensions as the size and weight of the rails require. They are fastened to the switch rails in various ways. In Fig. 4, the connection is made by means of cast-steel sockets bolted to the webs of the rails. The head-rod is shown in detail at (*b*). The cast-steel sockets *n* and *n'* extend low enough to permit the head-rod to pass under the rails, as shown in the detail. The head-rod is fastened to each socket with two bolts, while the other switch rods are single-bolted.

The rails *A A'* and *B B'* are spiked only on the outsides of the rails, and, to prevent the rails from getting out of line, the slide plates are bent upwards at the outside of the rail, forming the lip *o* [see Fig. 4 (*c*)], which holds the rail brace *p* solidly against the stock rail.

The connection-rod *q* is fastened at one end to the head-rod and at the other end to the crank *r* of the switch stand, shown in Fig. 4 (*d*). The switch stand rests on two cross-ties *s* and *s'*, being securely fastened to them either with bolts or track spikes. The switch stand consists of the column-shaped support *t*, the lever *u* used in throwing the switch, the target *v*, and the crank-shaft *r*.

The target *v* consists of two rectangular pieces of sheet iron fastened to the target rod at right angles to each other. One half of the target is usually painted *white*, indicating **safety**, and the other half *red*, indicating **danger**. They are so adjusted that an open switch always indicates danger.

The great advantages of the point switch are its *stiffness* and *safety*. When the switch is set for the siding, as shown in Fig. 3, the switch rail *CD* of the switch presses against the fixed outer main rail, and there is therefore no danger of vibration or looseness; the pressure of the wheel flange on the switch rail holds it firmly against the fixed main rail. When the switch is set for the main track, the point *A* of the switch rail is pressed against the rigid main rail at *A'*, and there is no tendency to vibration. The whole construction is thus very nearly as rigid as any part of the main track; the switch can therefore be operated at high speed in either direction, and for running along either the main track or the side track. The point switch is safer than the stub switch because, if it is wrongly set, the train will not be derailed. When the train is trailing the switch, the flanges of the wheels will usually spring the point of the switch rail out from the main rail sufficiently to allow the flanges to pass between them; while, if the train faces the misplaced switch, it will, of course, merely be turned on to the wrong track.

9. The Safety Switch.—Fig. 6 shows a form of switch that is much used; it is known as the **Lorenz**, or **safety, switch.** This is a self-acting switch provided with a powerful spring at *A*, which holds the switch point firmly against the spiked rail *C' D'*, thus keeping the main track constantly unbroken. With the switch points in this position, a train can

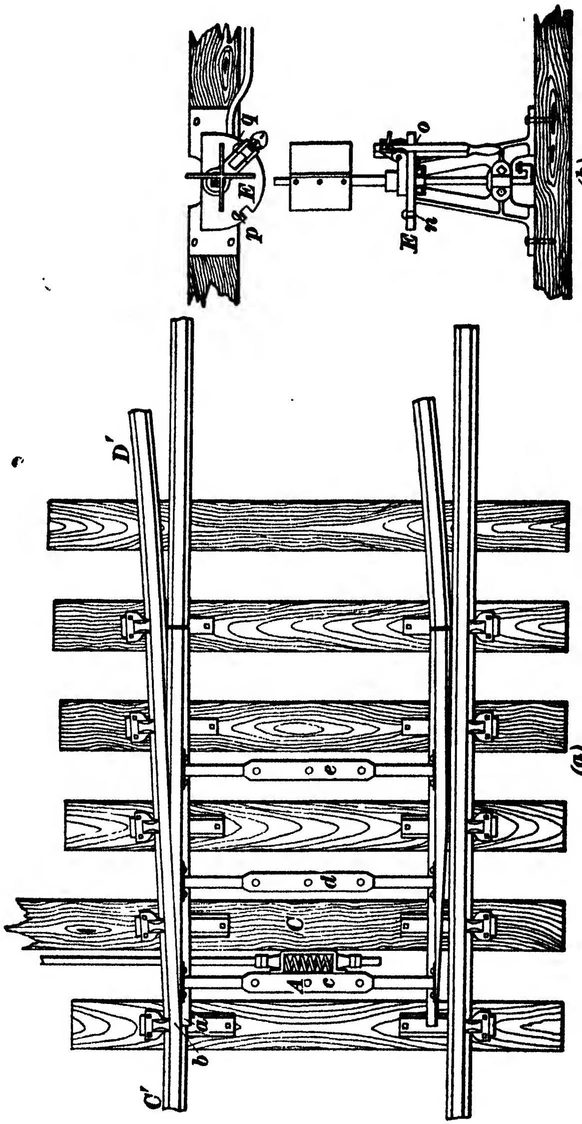


FIG. 6

make a trailing switch, the wheel flanges forcing the switch open as they pass from the side to the main track. As the spring is constantly acting, each wheel throws the switch, which instantly resumes its position for the main track. Except for the spring at *A*, this switch is practically identical with the point switch already described.

10. Tie-Rods and Head-Rods.—Common forms of tie-rods are shown in Fig. 7: the lugs *m n* are about 5 inches long and are bolted firmly to the webs of the switch rails. The tie-rod shown at (*a*) is hinged, so as to cause it to

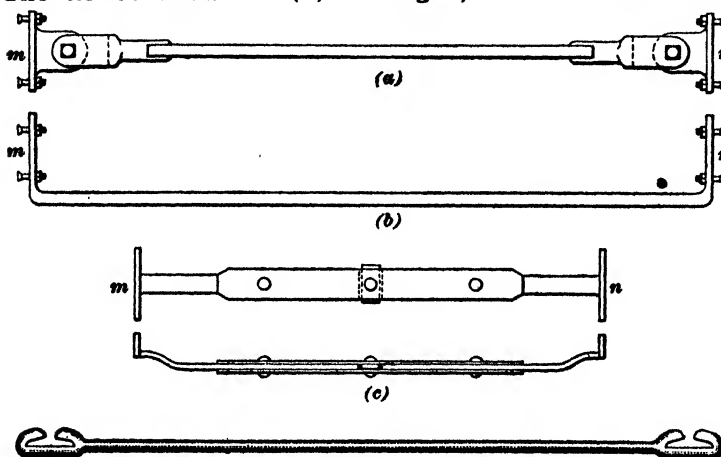


FIG. 7

operate more easily; an unhinged form is shown at (*b*). The tie-rod at (*c*) is shown in position in the track at *d* and *e*, Fig. 6. This form is bent downwards nearly to a level with the top of the tie, where it is less exposed to injury from derailed cars or from broken parts of the cars, such as brake rods or beams, which, dragging on the ties, frequently catch in switch rods, doing much harm. The form shown at (*d*) is used only with stub switches; the tie-rods are slipped over the ends of the rails, and fastened into place by hammering down the free ends of the prongs on the rail flange.

When forms (*a*) or (*b*), Fig. 7, are used for the tie-rods, the head-rod may be of the form shown in Fig. 4 (*b*);

when form (*c*) is used for the tie-rods, the head-rod is as shown in Fig. 6 (*a*), the spring being sometimes omitted. A stub-switch head-rod is shown in position at *g*, Fig. 2.

11. Switch Stands.—The cheapest form of mechanism for moving the switch rails is known as the **ground lever.** It is illustrated in Fig. 8, and shown in position at *n m*, Fig. 2. It consists of a lever with a length of about 30 inches, which operates a connecting-rod *A B*, joined to a pin *C* in the lever; the pin swings in a circle whose diameter is exactly equal to the throw of the switch. The principle of this device has the great advantage that the lever is horizontal for either position of the switch. It is therefore practically self-locking, although a padlock is commonly used to fasten it in either

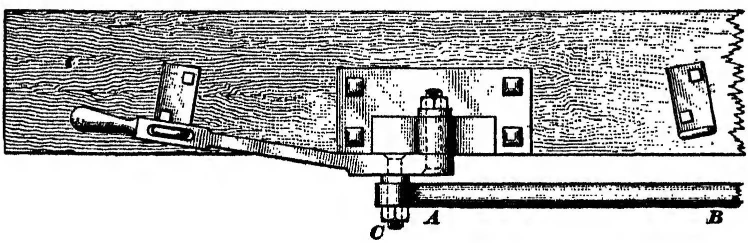


Fig. 8

position to prevent malicious tampering. This type of switch stand is well suited to both stub and split switches, and on account of its compactness is especially suited to yard work.

12. More complicated forms of switch stands are provided with a target, which is turned by the mechanism that moves the switch, and exhibits a white target when the switch is set for the main track, and a red target when the switch is set for the siding. Two forms of such targets are shown in Fig. 4 (*d*) and Fig. 6 (*b*), respectively.

In the form of target shown in Fig. 4 (*d*), the lever *u* carries a *cam* or eccentric-shaped disk *w* that, when in the position *u*, fits between lugs *x*; the lugs are bolted to the pedestal *t*, and form a part of the rigid stand. When the lever is in the position *u*, the switch may be locked, holding the switch firmly in place. To throw the switch,

the lever is raised to the position u'. This releases the cam w from the lug x, and, the lever being clamped to the target rod or shaft y, any movement of the lever u is communicated to the crank r, which, by means of the connection-rod q, acts directly on the switch rails.

13. A common form of yard stand used with safety switches is shown in plan and elevation in Fig. 6 (b). The target is about 4 feet above the ground, and is provided with an attachment for a signal lamp. The lever is hinge-jointed, and, in throwing the switch, the lever is brought into a horizontal position, resting on the semicircular iron latch plate E. In the edge of this plate are two slots n, o, in which the lever fits after the switch is thrown. Lugs p and q at the sides of the slots limit the lateral movement of the lever. The switch stand is secured to the head-block by either bolts or track spikes—usually the latter.

FROGS AND GUARD-RAILS

14. Description and Action of Frogs.—A **frog** is a combination of rails so arranged that the broad tread $A B$

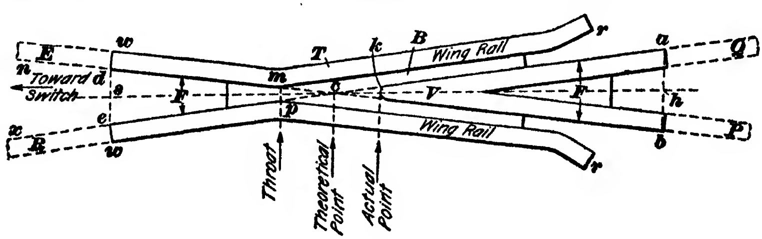


FIG. 9

of the wheel, Fig. 5, will always have a surface on which to roll, and so that the flange of the wheel will have a channel through which to pass. A frog is shown in position on the track at K, Fig. 1, and a larger plan of the part at $a b$, Figs. 1 and 3, is shown in Fig. 9: EP is the inner rail of the main track, and RQ is the outer rail of the side track. When the train is running on the main track, the flanges of the inner wheels press against the gauge line $n m$, the treads being supported by the rail head. On reaching m, the flanges

continue to move along the line *m c b*, being prevented from entering the channel *B*, or **riding the frog** at *V*, by the guard-rail at *R′*, Fig. 1. While the flanges are moving past the frog along *m b*, the treads are supported on the portions of rails at *T* and *V*.

When the train is entering the turnout, the flanges of the outer wheels press against the gauge line *x c a*, the guard-rail at *R*, Fig. 1, causing them to enter the channel *B*, Fig. 9, and to pass the frog safely.

15. The wedge-shaped part *a k b* of the frog is called the **tongue** of the frog, and its point *k* is called the **actual point of frog.** The actual point of frog is somewhat shortened and rounded. The intersection *c* of the outside edges *a c* and *b c* of the tongue is called the **theoretical point of frog.** When the point of frog is referred to, the theoretical point is usually meant. The bent rails *w r* are called **wing rails**; the narrowest part *m p* of the frog is called the **throat.** The throat of the frog must be wide enough to allow the flanges of the wheels to pass through; it is usually made about 2 inches wide.

16. Plate and Keyed Frogs.—Frogs are usually made of rails of the same weight and cross-section as the rails in the main track. The rails are planed down to the proper form, and also bent; they are then either bolted and keyed together, using cast-iron separators in order to properly allow for the flange spaces and the throat, or they are riveted to a flat plate on which they all rest; the latter method, however, is used only for light-traffic work. Frogs in which all the parts are rigidly fastened, and are, therefore, immovable, are called **stiff frogs.** Those in which one of the wing rails is movable, and is controlled by means of a spring, are called **spring frogs.** Stiff frogs contain much less material and require less shop work than spring frogs. For a given angle, a stiff frog requires less space, and hence is better adapted to yard work than spring frogs. Stiff frogs are more simply constructed than spring frogs, and can be made at any well-equipped machine shop.

Figs. 10 and 11 represent the best types of stiff frogs. The frog shown in Fig. 10 is called a **plate frog.** The rails composing the frog are fastened to a plate *a c d b* of wrought iron or steel by means of rivets through the rail flanges, as shown in the figure. Square holes *e*, *f* are punched in the plate to receive the railroad spikes, which are driven into

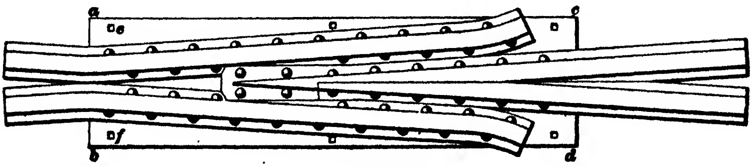
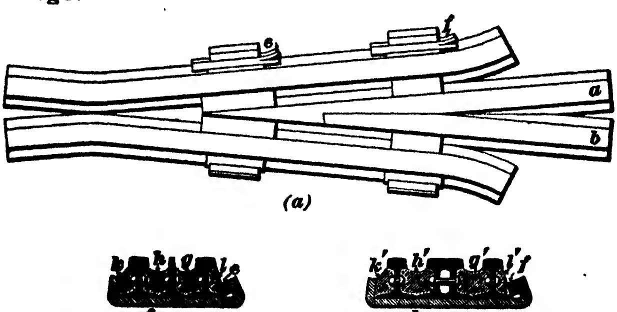


Fig. 10

the cross-ties supporting the frog, holding it firmly in place. Plate frogs are perfectly rigid, and by many railroad men are considered inferior to the **keyed frog,** shown in Fig. 11, which is somewhat flexible and better suited to yard work where the curves are sharp and the frog angles correspondingly large.



(a)

(b) Fig. 11 (c)

In this frog, the pieces of rails *a* and *b*, forming the tongue, are dovetailed together and secured by heavy rivets. To retain the full strength and durability of the steel, all the parts are fitted without heating, except the wings, which are bent at a very low heat. The parts are bound by heavy wrought-iron clamps *c* and *d*, shown at (*b*) and (*c*), (*b*) being a cross-section through the first clamp, and (*c*) one through the second clamp. These clamps are tightened by means

of beveled split keys, or wedges, *e* and *f*, the ends of the clamps being bent over a form to an exact angle, at one end to fit the brace-blocks k, k' on the outside of the rail, and at the other end to fit the beveled keys, which are driven into the spaces between the end of the clamp and the smaller brace-blocks l, l'. The keys lie on the flange of the rail, which prevents them from dropping down in case they loosen. The flange way between the frog point and the wing rails is maintained by iron throat-pieces g, h, g', h' that fit the rails perfectly and, extending to the point, thoroughly brace it against lateral stresses. After the keys are driven to the extent necessary to bind the parts solidly together, the split ends are spread to prevent the keys from working out.

From its peculiar construction, this frog has the same elasticity as the rails in the track, which makes it an easy riding frog, more durable than a plate frog and less liable to injury from uneven ballasting. It presents little obstruction to tamping, and, when fastened into the track with the usual angle splices, it is firm, stable, and free from any tendency to jump or move.

17. Spring Frogs.—In spring frogs, one of the wing rails is spiked firmly to the ties, and the other wing rail is movable, being held close against the tongue of the frog by a powerful spring.

A common form of spring frog is shown in Fig. 12. In this figure, $w' r'$ is the fixed wing rail, which is spiked to the ties throughout its whole length. The tongue $V C V'$ of the frog is also firmly spiked to the ties. The flange way between the tongue rail $C V$ and the fixed wing rail $w' r'$ is maintained by a closely fitting iron throat-piece $e f$, Fig. 12 (*a*), also shown in section at *e*, Fig. 12 (*b*), and at *f*, Fig. 12 (*c*). This throat-piece is prevented from slipping by the rivets and pins through the rails.

The movable wing rail $w r$ is called the **spring rail.** This rail is not spiked, but is held against the point of frog by the spring $H G$. If a train is running in the direction from V' to w', each wheel flange as it passes between C and r will

force the spring rail away from the frog point; the instant the wheel flange passes the frog point Y, the rail $w\,r$ springs back into place. Similarly, if the wheel is moving from w' to V', when the flange reaches the throat of frog at W it will begin to force the spring rail away from the frog point, since the wheel is forced to follow the turnout rail $w'\,V'$ by the guard-rail, which lies opposite to the frog on the turnout track; this guard-rail is shown at R', Fig. 1.

The spring frog shown in Fig. 12 is provided with an **anchor block** $M\,N$; this is simply a **U**-shaped frame, shown in section at h, Fig. 12 (d), to which the ends both of the main-track rails and of the frog rails are bolted. When the anchor block is used, the ends w and w' of the frog rails always remain exactly opposite each other in the track. If no anchor block is used, the spring rail is liable to creep slightly, thus impairing the close joint that should exist between Y and r, and also subjecting the spring and spring bolt to unnecessary stress.

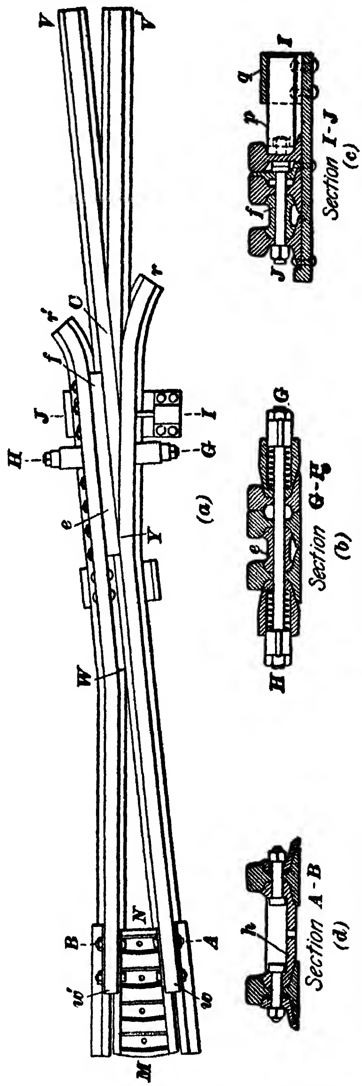


Fig. 12

The device shown at $J\,I$ is designed to prevent the free end r of the wing rail $w\,r$ from springing upwards: when a wheel passes over the end w, it tends to force this end

downwards and the free end upwards. To prevent this, the wrought-iron strip p, Fig. 12 (c), is firmly bolted to the web of the spring rail, and held in place by the collar q, so that it can readily move away from or toward the tongue of the frog, but cannot move upwards.

Spring frogs are far less injurious to rolling stock than stiff frogs, and should therefore be used on main-line tracks where the traffic is heavy. When a spring frog is used, the main line $w V$ is smooth and unbroken, and there is little jar in crossing the frog.

18. Frog Angle and Frog Number.—The angle $a c b$, Fig. 9, between the outside edges of the tongue of the frog is called the **frog angle.** This is also equal to the angle $d c e$ between the outside edges of the tongue produced beyond c. The frog angle is represented by F.

Since $n c b$ is the gauge line of the inner rail of the main track, and $x c a$ is the gauge line of the outer rail of the side track, the frog angle is also equal to the angle between the two tracks.

The distance $a b$ between the gauge lines at the end of the tongue is called the **heel width**; the distance $d e$ is called the **mouth width.** If $s c h$ is the bisector of the angle F, the distance $c h$ is called the **length of frog.**

The ratio of the length to the heel width is called the **frog number,** and is usually denoted by n; that is,

$$n = c h \div a b$$

To find n when F is given, we have

$$n = \frac{c h}{a b} = \frac{1}{2} \frac{c h}{a h}$$

But in the triangle $a c h$,

$$\cot a c h = \cot \tfrac{1}{2} F = \frac{c h}{a h}$$

Therefore, substituting this value in the above expression for n,

$$n = \tfrac{1}{2} \cot \tfrac{1}{2} F, \qquad (1)$$

and, solving for $\cot \frac{1}{2} F$,

$$\cot \tfrac{1}{2} F = 2 n \qquad (2)$$

Frogs are designated by their numbers; thus, a No. 8 frog is one in which $n = 8$.

Although formulas **1** and **2** are easily applied, it is convenient to make use of a small table giving the frog angle corresponding to each frog number, and also the trigonometrical functions of this angle. Table I contains these quantities for all frog numbers and half numbers from 4 to 12.

TABLE I

FROG NUMBERS WITH THE CORRESPONDING FROG ANGLES AND THEIR TRIGONOMETRIC FUNCTIONS

Frog Number n	Frog Angle F	Nat. sin F	Nat. cos F	Log sin F	Log cos F	Log cot F
4.0	14° 15′ 00″	.24615	.96923	$\bar{1}.39120$	$\bar{1}.98642$	.59522
4.5	12 40 49	.21951	.97561	1.34145	$\bar{1}.98927$	.64782
5.0	11 25 16	.19802	.98020	$\bar{1}.29670$	$\bar{1}.99131$	.69461
5.5	10 23 20	.18033	.98360	$\bar{1}.25606$	$\bar{1}.99282$	.73675
6.0	9 31 38	.16552	.98621	$\bar{1}.21884$	$\bar{1}.99397$	.77513
6.5	8 47 51	.15294	.98823	$\bar{1}.18453$	$\bar{1}.99486$	.81033
7.0	8 10 16	.14213	.98985	$\bar{1}.15268$	$\bar{1}.99557$	.84288
7.5	7 37 41	.13274	.99115	$\bar{1}.12301$	$\bar{1}.99614$	.87313
8.0	7 9 10	.12452	.99222	$\bar{1}.09522$	$\bar{1}.99660$	.90138
8.5	6 43 59	.11724	.99310	$\bar{1}.06909$	$\bar{1}.99699$	.92790
9.0	6 21 35	.11077	.99385	$\bar{1}.04442$	$\bar{1}.99732$	.95289
9.5	6 1 32	.10497	.99448	$\bar{1}.02107$	$\bar{1}.09759$	.97652
10.0	5 43 29	.09975	.99501	$\bar{2}.99891$	$\bar{1}.99783$	.99892
10.5	5 27 9	.09502	.99548	$\bar{2}.97781$	$\bar{1}.99803$	1.02021
11.0	5 12 18	.09072	.99588	$\bar{2}.95770$	$\bar{1}.99820$	1.04050
11.5	4 58 45	.08679	.99623	$\bar{2}.93848$	$\bar{1}.99836$	1.05987
12.0	4 46 19	.08319	.99653	$\bar{2}.92007$	$\bar{1}.98849$	1.07842

EXAMPLE 1.—To find the frog angle of a No. 7 frog.

SOLUTION.—From formula **1**, since $n = 7$,

$$\cot \tfrac{1}{2} F = 2 \times 7 = 14$$

Therefore, $\tfrac{1}{2} F = 4° 5' 8''$; $F = 8° 10' 16''$. Ans.

The same result can be taken directly from Table I.

EXAMPLE 2.—If the frog angle is 7°, what is the frog number?

SOLUTION.—From formula **1**, we have

$$n = \tfrac{1}{2} \cot \frac{7°}{2} = \tfrac{1}{2} \cot 3° 30' = 8.2, \text{ nearly. Ans.}$$

This problem cannot be solved directly by Table I; it can, however, be readily solved by interpolation as follows:

Looking in the second column, it is found that 7° lies between 6° 43′ 59″ and 7° 9′ 10″, or the angles corresponding to No. 8.5 and No. 8 frogs, respectively. The difference between these two angles is 25′ 11″, or 1,511″. The difference between 7° 9′ 10″ and 7°, the given angle, is 9′ 10″, or 550″. Hence, $\frac{550}{1511}$ of .5 must be added to 8 to find the number of the frog corresponding to a frog angle of 7°.

$$\tfrac{550}{1511} \times .5 = .2, \text{ nearly}$$

The required number is 8 + .2, or 8.2, nearly, as found before.

However, as standard frogs are made in whole numbers and halves, unless a special frog is to be made to order, the nearest half number is taken from the table without interpolating.

In this case, looking in the second column of the table, it is found that the frog angle whose value is most nearly equal to 7° is 7° 9′ 10″, and the corresponding frog number is 8.

EXAMPLE FOR PRACTICE

Solve the following problems both by the formulas and by the table:

(*a*) If $n = 6$, find F.
(*b*) If $n = 9\frac{1}{2}$, find F.
(*c*) If $F = 5° 44′$, find n.
(*d*) If $F = 4° 58′ 45″$, find n.

Ans. (*a*) 9° 31′ 38″; (*b*) 6° 1′ 32″; (*c*) 10, nearly; (*d*) $11\frac{1}{2}$

---

19. To Find the Number of a Frog by Measurement.—Fig. 9 gives

$$ch = ah \cot \tfrac{1}{2} F$$
$$cs = ds \cot \tfrac{1}{2} F$$

Therefore, by addition,

$$ch + cs = (ah + ds) \cot \tfrac{1}{2} F$$
$$= \left(\frac{ab}{2} + \frac{de}{2}\right) \cot \tfrac{1}{2} F$$

But $ch + cs = sh$; and, from the preceding article, $\frac{1}{2} \cot \frac{1}{2} F = n$. Therefore, substituting these values,

$$sh = (ab + de)\, n;$$

whence

$$n = \frac{sh}{ab + de}$$

If the whole distance sh and the widths ab and de are measured on the frog and their values substituted in this formula, the result will be the frog number.

By this method, n may be found much more accurately than by attempting to measure $c h$ and $a h$ on the frog, because the theoretical point c of frog cannot be accurately found in practice. On some roads, the frogs are still numbered arbitrarily, or according to their length in feet, while on others they are designated by letters of the alphabet.

EXAMPLE.—The distance $s h$ was measured on a frog and found to be 7 feet 4 inches. The heel width $a b$ was 15 inches, and the mouth width $d e$ was 7 inches. What was the frog number?

SOLUTION.—Substituting the values in the formula just derived,

$$n = \frac{7 \text{ ft. } 4 \text{ in.}}{15 \text{ in.} + 7 \text{ in.}} = \frac{88 \text{ in.}}{22 \text{ in.}} = 4. \quad \text{Ans.}$$

20. Guard-Rails.—Guard-rails, such as are shown at R and R', Figs. 1 and 3, must be used opposite the frog both on the main track and on the switch track. Such rails are usually 10 to 15 feet long. The clear space between the head of the guard-rail and the head of the main rail or switch should be slightly in excess of the width of the wheel flanges; usually it is made 2 inches. When two rails of ordinary weight—say 80-pound rails—are placed with their flanges edge to edge, the heads of the rails will be $2\frac{1}{2}$ inches apart. Since about $\frac{3}{4}$ inch more must be allowed for spikes, the inner flange of the guard-rail must be cut away for about $1\frac{1}{4}$ inches, so that the head of the guard-rail will be 2 inches from the head of the main rail.

FORMULAS AND CALCULATIONS

21. Radius and Lead of a Turnout for Stub Switches.—Let $R N$, Fig. 13, be the main track and $Q P$ the turnout. Let Q be the point of switch and K the point of frog. If a stub switch is employed, the main-track rails will be securely spiked along $Y B$ and $L D$; the parts $B G$ and $D V$ of these rails will be movable, so that they may be bent outwards to meet the turnout rails W and Z. Here, then, the ends B and D are the heels of the switch, and G and V are the toes. The head-block is underneath G and V. In this figure, as in all similar figures of this

Section, the full lines represent the gauge lines of the track, which are the inside edges of the heads of the rails.

When the switch is thrown to run trains over the turnout, the track $BDZW$ becomes a simple circular curve, whose P. C. is at Q and whose radius is the radius of the turnout. The smaller the radius of the turnout, the larger will be the angle ZKX between the rail Z and the main-track rail YX, and therefore the larger will be the angle of the frog required at K. In order to lay out a turnout when the frog angle is given, it is therefore necessary to find a formula giving the radius in terms of the frog angle, and it is also necessary to find the distance BK from the point of frog to the heel of switch.

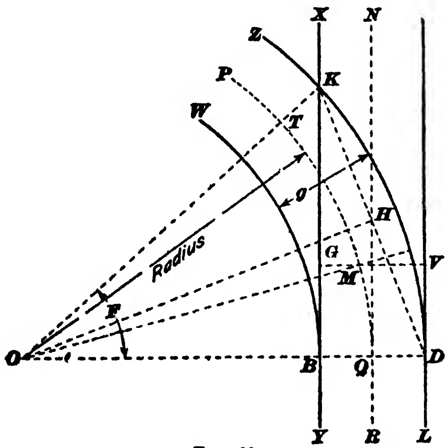


FIG. 13

The distance BK, measured along the main-track rail, from the point of frog to the heel of switch is called the **lead.** In the formulas given in this and in subsequent articles, the lead will be represented by L.

Let O, Fig. 13, be the center of the turnout curve; draw OD, OK, and DK, and let DK meet RN in H. Then, in the triangles DHQ and DKB,

$$\frac{HD}{KD} = \frac{QD}{BD} = \frac{QD}{2QD} = \tfrac{1}{2}$$

Therefore, $HD = \tfrac{1}{2}KD$, and H is the middle point of KD.

Draw OH. Since H is the middle point of KD, $HOD = \tfrac{1}{2}KOD$. But the angle KOD = the frog angle F, since its sides are respectively perpendicular to the frog rails ZK and KB. Therefore, angle $HOD = \tfrac{1}{2}F$.

In the triangle BDK,

$$BK = BD \tan BDK$$

But BK = the lead L, BD = the gauge g, and $BDK = 90° - HOD = 90° - \frac{1}{2}F$. Therefore, substituting these values,

$$L = g \tan(90° - \tfrac{1}{2}F),$$

or
$$L = g \cot \tfrac{1}{2}F \qquad (1)$$

From formula **2**, Art. **18**,

$$\cot \tfrac{1}{2}F = 2n$$

and, therefore, by substituting this value in formula **1**,

$$L = 2gn \qquad (2)$$

By formulas **1** and **2**, the lead may be found when the frog angle or the frog number is known.

To find the radius $r = OT$ of the center line of the turnout, we have, in the triangle OQH,

$$r = QH \cot HOQ \qquad (1)$$

But, from the triangles KBD and HQD, $\frac{QH}{BK} = \frac{QD}{BD} = \frac{QD}{2QD} = \frac{1}{2}$; therefore, $QH = \frac{1}{2}BK = \frac{1}{2}L$; and $\cot HOQ = \cot \frac{1}{2}F$. Substituting these values in equation (1),

$$r = \tfrac{1}{2}L \cot \tfrac{1}{2}F$$

By replacing in this equation the value $\frac{1}{2}L = \frac{1}{2}g \cot \frac{1}{2}F$ from formula **1**, we obtain

$$r = \tfrac{1}{2}g \cot^2 \tfrac{1}{2}F \qquad (3)$$

Since, from formula **2**, Art. **18**, $\cot \frac{1}{2}F = 2n$, we have, also,

$$r = 2gn^2 \qquad (4)$$

By formulas **3** and **4**, the value of the radius may be found when the frog angle or frog number is known.

The *standard gauge* of track is 4 feet 8½ inches = 4.708 feet.

EXAMPLE. 1—To find the radius of a turnout from a straight track for a No. 8 frog, if a stub switch is to be employed.

SOLUTION.—Substituting the values $n = 8$ and $g = 4.708$ in formula **4**,

$$r = 2 \times 4.708 \times 8^2 = 602.62 \text{ ft. Ans.}$$

EXAMPLE 2.—To find the lead in the turnout of example 1.

SOLUTION.—Substituting the given values in formula **2**,

$$L = 2 \times 4.708 \times 8 = 75.33 \text{ ft. Ans.}$$

EXAMPLES FOR PRACTICE

1. Find the lead for a No. 7 frog. Ans. 65.91 ft.
2. Find the radius for a No. 9 frog. Ans. 762.70 ft.
3. Find the lead and radius for a No. 4 frog. Ans. $\begin{cases} L = 37.66 \text{ ft.} \\ r = 150.66 \text{ ft.} \end{cases}$
4. Find the lead and radius if the frog angle is 4° 46′ 19″.

Ans. $\begin{cases} L = 113.00 \text{ ft.} \\ r = 1{,}356.0 \text{ ft.} \end{cases}$

---

22. Length of Switch Rails for Stub Switches. The length of the switch rails BA and CD, Fig. 1, depends on the sharpness of the curve of the turnout; the less the radius of this curve, the shorter the switch rails will be.

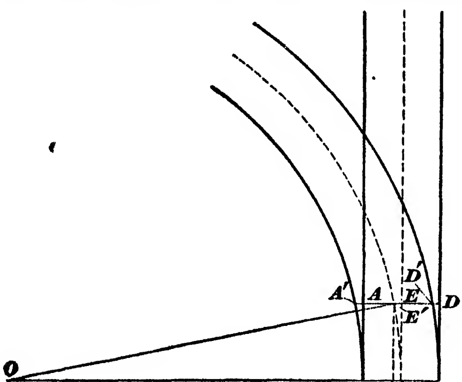


FIG. 14

In Fig. 14, let B and C be the heels of switch, A and D the toes, $AA' = DD' = EE'$ the throw, and $CD = BA = l$ the length of switch rails. From the figure, $EE' = MN = OM - ON$.

Let t = throw of switch = EE', and let $l = ME'$. The difference in length between ME' and NE' is too small to be appreciable in practice, so that we may also write $NE' = l$. From the triangle $E'ON$,

$$ON^2 = OE'^2 - E'N^2 = r^2 - l^2$$

Therefore, $t = OM - ON = r - \sqrt{r^2 - l^2}$;

whence $(r - t)^2 = (r^2 - l^2)$

and $l^2 = 2rt - t^2 = t(2r - t)$ **(1)**

The throw seldom exceeds $5\frac{1}{2}$ inches. In this formula, the the term t^2 is very small in comparison with $2r$, and may be dropped, without any appreciable error; so that we may write

$$l^2 = 2rt,$$

and, therefore, $l = \sqrt{2rt}$ **(2)**

TABLE II

DIMENSIONS OF STUB-SWITCH TURNOUTS

Track Circular From Heel of Switch to Point of Frog. Throw = $5\frac{1}{2}$ Inches

Frog Number n	Frog Angle F	Lead L	Chord (QT)	Radius	Degree of Curve d	Length of Switch Rails	Distance Ka, Fig. 1
4.0	14° 15′ 00″	37.67	37.38	150.67	38° 46′	11.73	1.50
4.5	12 40 59	42.37	42.12	190.69	30 24	13.19	1.69
5.0	11 25 16	47.08	46.85	235.42	24 32	14.65	1.87
5.5	10 23 20	51.79	51.58	284.85	20 13	16.15	2.06
6.0	9 31 38	56.50	56.30	339.00	16 58	17.64	2.25
6.5	8 47 51	61.21	61.03	397.85	14 26	19.09	2.44
7.0	8 10 16	65.92	65.75	461.42	12 26	20.53	2.62
7.5	7 37 41	70.62	70.47	529.69	10 50	22.03	2.81
8.0	7 9 10	75.33	75.19	602.67	9 31	23.48	3.00
8.5	6 43 59	80.04	79.90	680.36	8 26	24.93	3.19
9.0	6 21 35	84.75	84.62	762.75	7 31	26.43	3.37
9.5	6 1 32	89.46	89.33	849.85	6 45	27.97	3.56
10.0	5 43 29	94.17	94.05	941.67	6 5	29.37	3.75
10.5	5 27 9	98.87	98.76	1,038.19	5 32	30.85	3.94
11.0	5 12 18	103.58	103.47	1,139.42	5 02	32.31	4.12
11.5	4 58 45	108.29	108.19	1,245.36	4 36	33.78	4.31
12.0	4 46 19	113.00	112.90	1,356.00	4 14	35.17	4.50

By this formula the length to be given to the switch rails can be found when the radius and throw are known. The throw is usually $5\frac{1}{2}$ inches, or $\frac{11}{24}$ foot.

The values of l corresponding to the different radii employed with turnouts computed for standard frog numbers may be tabulated. These values will be found in the seventh column of Table II. The numbers of this table were computed from the accurate formula **1**, and may, therefore, differ by a few hundredths of a foot from the values obtained by formula **2**. This difference is of no practical importance.

EXAMPLE.—If the throw is $5\frac{1}{2}$ inches and the radius 339 feet, what is the length of the switch rails?

SOLUTION.—Substituting $r = 339$ and $t = \frac{11}{24}$ ft. in formula **2**,

$$l = \sqrt{2 \times 339 \times \tfrac{11}{24}} = 17.63 \text{ ft. Ans.}$$

The table gives $l = 17.64$ ft.

23. Table for Stub-Switch Turnouts.—Table II gives the dimensions for laying out a turnout when a stub switch is employed. The first column contains the frog numbers, varying by halves, from 4 to 12; the second column contains the corresponding frog angles, computed by formula **2**, Art. **18**; the third column gives the value of the lead BK, Fig. 13, computed by formula **2**, Art. **21**; the fourth column gives the length of the chord QT, Fig. 13, which, from this figure, is equal to $2 \times OT \times \sin TOH = 2r \sin \frac{1}{2}F$; the fifth and the sixth column contain, respectively, the radius and degree of curve of the center line QT, Fig. 13, of the turnout; the radius is computed by formula **4**, Art. **21**, and the corresponding degree of curve by the familiar formula $d = \dfrac{5{,}730}{r}$; the seventh column contains the length of switch rail computed by formula **1**, Art. **22**; the last column of the table contains the distance cw, Fig. 9, from the theoretical point of frog to the end of the frog rail. This is the distance Ka in Fig. 1. With different forms of frogs, this length is frequently somewhat different from that given in the table; the engineer should, therefore, measure it for the different frogs that he will employ. A knowledge

of this distance is important, because, when the lead BK, Fig. 1, and the length BA of the switch rail have been found, the exact length Aa of spiked rail can be readily obtained. To obtain the proper length Aa, it is usually necessary to cut one or more rails before beginning to lay the turnout.

EXAMPLE.—To find the dimensions of a stub switch using a No. 6 frog.

SOLUTION.—From the third column of Table II, the lead is 56.50 ft., and the radius, from the fifth column, is 339 ft. The length of the switch rail, from the seventh column, is 17.64 ft. Therefore, the distance AK, Fig. 1, from the toe of the switch to the point of frog is $56.50 - 17.64 = 38.86$ ft. From the last column, the length Ka, Fig. 1, of frog rail is 2.25 ft. The length Aa of plain rail required is, then, $38.86 - 2.25 = 36.61$ ft. As a rail of this length is not obtainable under ordinary circumstances, it must be made from two rails. These two rails should preferably be of approximately equal length; this gives better results than the use of a full-length rail (which is sometimes 33 ft. long) spliced to a short piece 3 or 4 ft. long. Pieces of rail shorter than 10 ft. should be avoided when possible.

EXAMPLE FOR PRACTICE

Find, from Table II, the dimensions of the two following stub-switch turnouts:

(*a*) Switch with a No. 5 frog.
(*b*) Switch with a No. 7 frog.

Ans. { (*a*) $L = 47.08$, $r = 235.42$, $l = 14.65$, $AK = 32.43$, $Ka = 1.87$, $AC = 30.56$ ft.
(*b*) $L = 65.92$, $r = 461.42$, $l = 20.53$, $AK = 45.39$, $Ka = 2.62$, $Aa = 42.77$ ft.

---

24. Turnout Dimensions for Point Switches.—Let MN, Fig. 15, be the center line of the main track and MJ that of the turnout. Let BA and CD be the two switch rails whose fixed ends, or heels, are at B and C, and whose toes are at A and D. These rails are usually of a uniform length of 15 feet, except for the sharpest curves.

The center line MIJ will, when a point switch is used, have a somewhat different position from that which it has when a stub switch is employed. In the stub-switch turnout,

the rails $A'TU$ and DCK are bent to a uniform curve between M and J; in a point switch, the outer rail is made up of a straight part DC, which is the switch rail, and a curved part CE, which is tangent to DC at C. On this account, the lead $A'K$ is less with a point switch than with a stub switch.

Since point switches are used on the main line where very accurate work is required, it is necessary to take account of the fact that the short frog rails are not curved, the part EE' of the rail being straight.

In computing the dimensions of a point-switch turnout, the usual data are the length $AB = DC$ of the switch rail, and the angle CDP between the outer switch rail and the main rail DR. This angle is called the **switch angle,** and will be represented by S. The frog number or the frog angle must also be known, as well as the length of the straight part EE'. It is then required to determine the radius OI of the center line of a turnout whose outer rail shall be tangent to the switch rail DC at C and to the frog rail EE' at E, and to find the lead $A'K$ of this turnout.

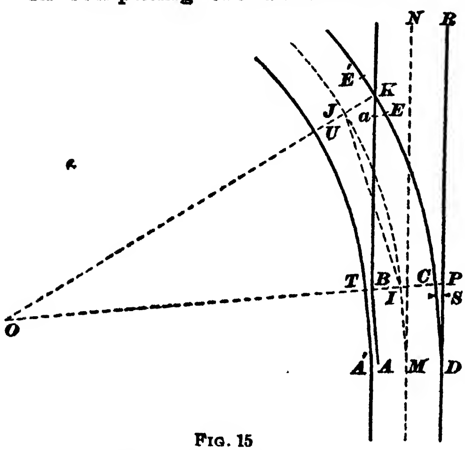


FIG. 15

The formulas for computing these quantities are so complicated that, in practice, tables giving the various dimensions of point switches are always employed.

Table III, which is similar to Table II for stub switches, contains all the dimensions necessary for laying out a point switch when the frog number is known. It contains the frog angle, the switch angle CDP, Fig. 15, the lead $A'K$, the radius OI of the center line of the turnout, the degree of curve of this center line, the chord JI, the length $AB = CD$

TABLE III

DIMENSIONS OF POINT-SWITCH TURNOUTS

Turnouts With Straight Point Rails and Straight Frog Rails; Gauge 4 Feet $8\frac{1}{2}$ Inches

Frog Number n	Frog Angle F	Switch Angle (CDP)	Lead L $(A'K)$	Radius r	Degree of Curve d	Chord (JI)	Length of Switch Rails (CD)	Length of Straight Frog-Rail (KE)
4.0	14° 15′ 00″	3° 40′	32.20	125.21	47° 05′	23.09	7.5	1.50
4.5	12 40 49	3 40	34.29	159.25	36 36	25.03	7.5	1.69
5.0	11 25 16	2 45	41.85	197.65	29 22	29.88	10.0	1.87
5.5	10 23 20	2 45	44.16	240.44	24 00	32.03	10.0	2.06
6.0	9 31 39	1 50	56.00	288.09	19 59	38.66	15.0	2.25
6.5	8 47 51	1 50	58.84	340.19	16 54	41.34	15.0	2.44
7.0	8 10 16	1 50	61.65	397.65	14 27	43.98	15.0	2.62
7.5	7 37 41	1 50	64.36	460.00	12 29	46.50	15.0	2.81
8.0	7 9 10	1 50	67.04	527.91	10 52	48.99	15.0	3.00
8.5	6 43 59	1 50	69.60	600.94	9 33	51.38	15.0	3.19
9.0	6 21 35	1 50	72.20	681.16	8 25	53.80	15.0	3.37
9.5	6 1 32	1 50	74.70	767.11	7 28	56.11	15.0	3.56
10.0	5 43 29	1 50	77.04	858.14	6 41	58.28	15.0	3.75
10.5	5 27 9	1 50	79.51	959.00	5 59	60.57	15.0	3.94
11.0	5 12 18	1 50	81.82	1,065.52	5 23	62.69	15.0	4.12
11.5	4 58 45	1 50	84.09	1,180.16	4 51	64.78	15.0	4.31
12.0	4 46 19	1 50	86.16	1,299.93	4 24	66.67	15.0	4.50

of the switch rails, and the length $KE = Ka$ of the straight frog rail.

EXAMPLE.—To find the dimensions of a point-switch turnout for a No. 8.5 frog.

SOLUTION.—From Table III we have: switch angle $= CDP = S = 1° 50'$; lead $= A'K = L = 69.60$ ft.; length of switch rails $BA = CD = l = 15$ ft.; length of straight frog rail $KE = Ka = 3.19$ ft. Therefore,

$$BK = 69.60 - 15.0 = 54.60 \text{ ft.}$$

and the length of straight rail

$$Ba = 54.60 - 3.19 = 51.41 \text{ ft.}$$

From the table, radius $OI = r = 600.94$ ft., and degree of curve $d = 9° 33'$.

EXAMPLE FOR PRACTICE

Find the dimensions of the two following point-switch turnouts:

(*a*) Switch with No. 4 frog.

(*b*) Switch with No. 12 frog.

Ans. $\begin{cases} (a)\ S = 3° 40',\ L = 32.20,\ l = 7.5,\ Ka = 1.50,\ BK = 24.70, \\ \quad Ba = 23.20,\ r = 125.21,\ d = 47° 5' \\ (b)\ S = 1° 50',\ L = 86.16,\ l = 15.0,\ Ka = 4.50,\ BK = 71.16, \\ \quad Ba = 66.66,\ r = 1{,}299.93,\ d = 4° 24' \end{cases}$

---

25. Turnout From the Outer Side of a Curved Track: Theoretical Formulas.—Let HE, Fig. 16, be the center line of the main track, and He the center line of the turnout. Let B and C be the heels of switch, K the point of frog, D the center of the main-track curve, and O the center of the turnout curve.

The distance BK from the heel of switch to the point of frog is the lead of the turnout. In order to lay out the turnout, the radius $DE = DH = R$ of the main track, and also the frog angle, must be known, and from these the lead BK and the radius $OH = Oe = r$ of the center line of the turnout must be computed.

In this article, the complete formulas for finding r and BK are derived, but these formulas are seldom used in practice. A practical method of finding the dimensions of the turnout is given in a subsequent article.

1. *To Find the Radius r of the Center Line of the Turnout.* In the triangle KCD, Fig. 16, in which $M = CDK$,

$Q = DKC$ and $P = KCD$, we have, from trigonometry,

$$\tan \tfrac{1}{2}(P - Q) = \frac{DK - DC}{DK + DC} \cot \tfrac{1}{2} M;$$

whence

$$\cot \tfrac{1}{2} M = \frac{DK + DC}{DK - DC} \tan \tfrac{1}{2} (P - Q) \qquad (1)$$

But if $DH = DE = R$, and $BC = g$, then $DK = R + \frac{1}{2} g$ and $DC = R - \frac{1}{2} g$. Therefore, substituting these values in equation (1), we have

$$\cot \tfrac{1}{2} M = \frac{(R + \frac{1}{2} g) + (R - \frac{1}{2} g)}{(R + \frac{1}{2} g) - (R - \frac{1}{2} g)} \tan \tfrac{1}{2} (P - Q)$$

$$= \frac{2R}{g} \tan \tfrac{1}{2} (P - Q) \qquad (2)$$

Since the radii DK and OK are perpendicular, respect-

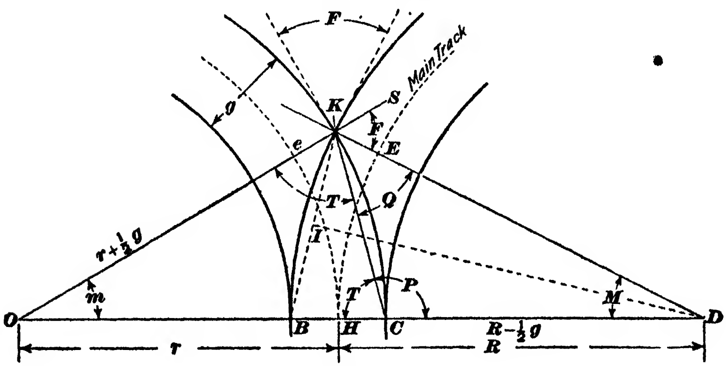


FIG. 16

ively, to the frog rails at K, the angle SKD between these radii is equal to the frog angle F.

The triangle KOC is an isosceles triangle, since the two sides OK and OC are equal. Hence, angle $OKC = OCK$. Let the angle $OKC = OCK$ be denoted by T. Then, at the point K,

$$T + Q + F = 180°,$$

and at the point C, $\quad T + P = 180°$

Therefore, equating these two expressions,

$$T + P = T + Q + F;$$

whence $\quad P - Q = F$

Substituting this value of $P - Q$ in equation (2),

$$\cot \tfrac{1}{2} M = \frac{2R}{g} \tan \tfrac{1}{2} F;$$

whence $$\tan \tfrac{1}{2} M = \frac{g}{2R} \cot \tfrac{1}{2} F \qquad \textbf{(1)}$$

Also, since $\frac{1}{2} \cot \frac{1}{2} F = n$ (Art. **18**),

$$\tan \tfrac{1}{2} M = \frac{g n}{R} \qquad \textbf{(2)}$$

From the triangle OKD,

$$OK = \frac{DK}{\sin KOD} \sin M \qquad (3)$$

But $OK = r + \frac{1}{2} g$, $DK = R + \frac{1}{2} g$, and, since the angle SKD is exterior to the triangle, $SKD = KOD + ODK$; that is, $F = KOD + M$, and $KOD = F - M$. Therefore, substituting these values in equation (3),

$$r + \tfrac{1}{2} g = \frac{R + \frac{1}{2} g}{\sin (F - M)} \sin M \qquad \textbf{(3)}$$

2. *To Find the Lead* $BK = L$.—If DI is drawn perpendicular to BK, it will bisect the angle M, and the triangle BDI gives

$$BI = BD \sin \tfrac{1}{2} M \qquad (4)$$

But $BI = \frac{1}{2} BK = \frac{1}{2} L$, and $BD = R + \frac{1}{2} g$. Substituting these values in equation (4),

$$\tfrac{1}{2} L = (R + \tfrac{1}{2} g) \sin \tfrac{1}{2} M;$$

whence $$L = 2 (R + \tfrac{1}{2} g) \sin \tfrac{1}{2} M \qquad \textbf{(4)}$$

When M has been found by formula **2**, the lead may be computed by formula **4.**

26. Practical Method of Finding r and L.—When the frog number has been chosen, the radius r of the turnout may be computed by formulas **2** and **3**, Art. **25**, and the degree of curve d of the turnout by the formula $d = \frac{5{,}730}{r}$. Unless the curvature of the main track is very sharp, this value of d will be practically the same as the value obtained by subtracting the degree of curve of the main track from the degree of curve taken from the sixth column of Table II. The lead computed by formula **4**, Art. **25**, is also always

practically the same as the lead taken from the third column of Table II. This is illustrated by the following example.

EXAMPLE.—From a 4° curve of the main track, a turnout is to be laid to the outside of the main-track curve, a No. 9 frog being employed. To find the lead of the turnout and the degree of curve of its center line.

SOLUTION BY USING FORMULAS **2**, **3**, AND **4**, ART. **25**.—In this example, $n = 9$, $g = 4.708$, and the radius R of the 4° main-track curve is 1,432.7 ft. Substituting these values in formula **2**, Art. **25**,

$$\tan \tfrac{1}{2} M = \frac{4.708 \times 9}{1{,}432.7}; \text{ whence } M = 3° \, 23' \, 20''$$

Substituting this value of M in formula **3**, Art. **25**, and also the value of F taken from Table I,

$$r + 2.35 = (1{,}432.7 + 2.35) \frac{\sin 3° \, 23' \, 20''}{\sin (6° \, 21' \, 35'' - 3° \, 23' \, 20'')};$$

whence $r = 1{,}634.4$ ft.

Therefore,

$$d = \frac{5{,}730}{r} = \frac{5{,}730}{1{,}634.4} = 3.506° = 3° \, 30' \, 20'', \text{ nearly. Ans.}$$

From formula **4**, Art. **25**,

$$L = 2\,(1{,}432.7 + 2.35) \sin \tfrac{1}{2}\,(3° \, 23' \, 20'') = 84.87 \text{ ft. Ans.}$$

SOLUTION BY USING TABLE II.—

Degree of curve from Table II, corresponding to No. 9 frog	= 7° 31′
Degree of main-track curve	= 4° 0′
Degree of curve of turnout	= 3° 31′

Ans.

The lead, from Table II, corresponding to a No. 9 frog is 84.75 ft. Ans.

The difference between the two results is of no practical importance.

27. Ordinarily, the curvature of the switch rails is as indicated in Fig. 16; that is, the main-track rails and the turnout rails curve in opposite directions. But if the curvature of the main track is very sharp, or the frog angle unusually small, it may happen that the rails of the main track and those of the turnout curve in the same direction. This condition is shown in Fig. 17.

In this case, the degree of curve, taken from Table II, will be less than the degree of curve of the main track; the difference between the two degrees of curve will, however, be equal to the degree of curve of the turnout, as before.

Finally, if the degree of curve taken from Table II is exactly equal to the degree of curve of the main track, then, by the practical method of Art. **26,** the degree of curve of the turnout will be zero. The turnout will then have no curvature, and its rails will be straight. The location will then be as shown in Fig. 13, where, however, QT will represent the main-line curve and QN the turnout.

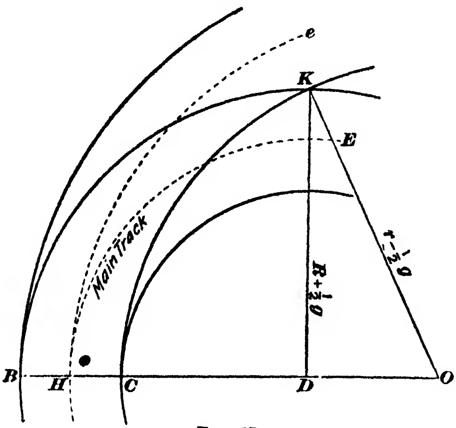


FIG. 17

28. Practical Directions for Finding the Dimensions of a Turnout to the Outside of a Main-Track Curve.—The method just described may be applied to both stub and point switches. For stub switches, Table II will be used; for point switches, Table III. The full directions for finding the dimensions of the turnout are as follows:

1. Take the value of the degree of curve from Table II for a stub switch, or from Table III for a point switch, corresponding to the given frog number. If this degree of curve is greater than the degree of curve of the main track, the turnout rails and main-track rails will curve in opposite directions (see Fig. 16); if less, they will curve in the same direction (see Fig. 17); if equal to the degree of curve of the main track, the turnout rails will be straight. The difference between the degree of curve taken from the table and the degree of curve of the main track will in each case be equal to the degree of curve of the turnout.

2. Take the value of the lead from Table II for a stub switch, or from Table III for a point switch, corresponding to the given frog number; this will be the required lead BK, Figs. 16 and 17, for the turnout from curved main track.

EXAMPLE 1.—To find the dimensions for a turnout to the outside of a curved main track if a point switch with a No. 8 frog is employed, the degree of curve of the main track being 4° 40′.

SOLUTION.—From Table III, the degree of curve corresponding to $n = 8$ is 10° 52′. As this is greater than 4° 40′, the turnout rails and main track rails curve in opposite directions (see Fig. 16). Therefore, the degree of turnout is

$$10° 52' - 4° 40' = 6° 12'. \quad \text{Ans.}$$

From Table III, corresponding to $n = 8$, we find, lead = 67.04 ft. Ans.

EXAMPLE 2.—To find the dimensions of a turnout to the outside of an 8° curve, if a point switch and a No. 10 frog are employed.

SOLUTION.—From Table III, the degree of curve is 6° 41′. Since this is less than 8°, the turnout rails and the main-track rails curve in the same direction (see Fig. 17). Therefore, the degree of curve of turnout is

$$8° - 6° 41' = 1° 19'. \quad \text{Ans.}$$

From Table III, corresponding to $n = 10$, we find, lead = 77.04 ft. Ans.

EXAMPLE FOR PRACTICE

In the following problems, let D represent the degree of curve of the main track, n the frog number, d the degree of curve of the turnout to be inserted, and L its lead; find in each case the value of d and that of L for a turnout to the outside of the main-track curve.

(*a*) $D = 5°$, $n = 8$, stub switch.
(*b*) $D = 7°$, $n = 7\frac{1}{2}$, stub switch.
(*c*) $D = 8°$, $n = 10\frac{1}{2}$, point switch.
(*d*) $D = 4°$, $n = 6$, point switch.
(*e*) $D = 6° 41'$, $n = 10$, point switch.

Ans. (*a*) $d = 4° 31'$, $L = 75.33$ ft.
(*b*) $d = 3° 50'$, $L = 70.62$ ft.
(*c*) $d = 2° 1'$, $L = 79.51$ ft. (see Fig. 17).
(*d*) $d = 15° 59'$, $L = 56.00$ ft.
(*e*) The turnout rails are straight, $L = 77.04$ ft.

---

29. Turnout to the Inner Side of a Curved Track. A turnout to the inner side of a curved track will lie as shown in Fig. 18, where HM is the center line of the main track and HN that of the turnout. The radius OR of the turnout is always less than the radius DH of the main

track; the degree of the turnout is, therefore, always greater than that of the main-track curve.

Such turnouts should be avoided, for, if the frog angle is small, the danger of derailment is very great; while if the frog angle is large, the curvature of the turnout is excessively sharp.

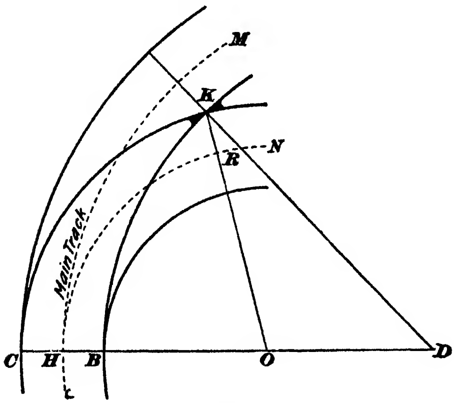


FIG. 18

The degree of curve of the center line HN of the turnout curve, and the lead BK are found as follows:

Rule I.—*Take from Table II for a stub switch, or from Table III for a point switch, the value of the degree of curve corresponding to the given frog number. Add this to the degree of curve of the main track. The sum is the degree of curve of the turnout.*

II. *Take the value of the lead from Table II for a stub switch, or from Table III for a point switch, corresponding to the given frog number. This will be the value of the lead BK, Fig. 18, desired.*

EXAMPLE.—To find the degree of curve and the lead of a turnout to the inside of a 4° curve if a No. 9 frog and a point switch are employed.

SOLUTION.—From Table III, the degree of curve corresponding to a No. 9 frog is found to be 8° 25′. Therefore, the degree of curve of the turnout is

$$4° + 8° 25' = 12° 25'. \text{ Ans.}$$

From Table III, the lead corresponding to a No. 9 frog is found to be 72.20 ft. Ans.

EXAMPLE FOR PRACTICE

In the following problems, find the degree of curve and the lead of the turnout to the inside of the main-track curve, if point switches are employed:

(*a*) Degree of main-track curve = 4°; frog number = 8.
(*b*) Degree of main-track curve = 5°; frog number = 10.

Ans. $\begin{cases} (a) & d = 14° 52', L = 67.04 \text{ ft.} \\ (b) & d = 11° 41', L = 77.04 \text{ ft.} \end{cases}$

CONNECTING CURVES

30. Connecting Curve Between Two Parallel Straight Tracks.—Let MN, Fig. 19, be the main track and ME the turnout. If the turnout is to connect with a side track DT' parallel to the main track, a curved track ED must be introduced to connect the turnout rails with the rails SG and RH of the side track. A curved track thus introduced to connect a turnout with a side track is called a **connecting curve.**

The frog number n and the distance $a = NT' = BD$ between the center lines of the parallel tracks must be known; the radius $r' = O_1D = O_1E$ of the center line of the connecting curve, and the distance KT from the point of frog to the point on the main track opposite to which the curve connects with the side track are to be computed. The distance a is usually taken as 13 feet.

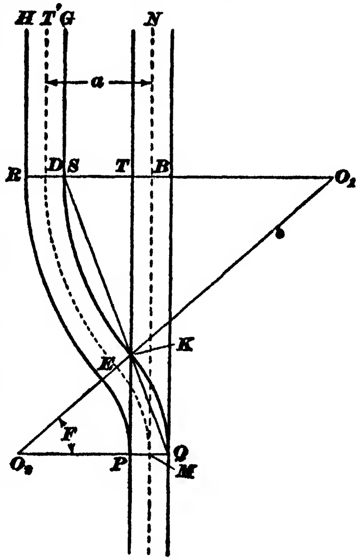


FIG. 19

If g is the gauge of track, the triangle O_1KT gives

$$O_1K = r' - \tfrac{1}{2}g \qquad (1)$$

$$O_1T = r' + \tfrac{1}{2}g - a \qquad (2)$$

By the principle of tangents,

$$\frac{\tan\frac{1}{2}(O_1TK + TKO_1)}{\tan\frac{1}{2}(O_1TK - TKO_1)} = \frac{O_1K + O_1T}{O_1K - O_1T} \qquad (3)$$

Now, $TO_1K = F$, since O_1T and O_1K are perpendicular to the rails of the frog. Also, $O_1TK = 90°$ and $TKO_1 = 90° - TO_1K = 90° - F$.

Substituting in equation (3) these values and those found in equations (1) and (2), there results

$$\frac{\tan \frac{1}{2}[90° + (90° - F)]}{\tan \frac{1}{2}[90° - (90° - F)]} = \frac{(r' - \frac{1}{2}g) + (r' + \frac{1}{2}g - a)}{(r' - \frac{1}{2}g) - (r' + \frac{1}{2}g - a)};$$

that is,

$$\frac{\tan(90° - \frac{1}{2}F)}{\tan \frac{1}{2}F} = \frac{2r' - a}{a - g};$$

or, since $\tan(90° - \frac{1}{2}F) = \cot \frac{1}{2}F$, and $\tan \frac{1}{2}F = \frac{1}{\cot \frac{1}{2}F}$,

$$\cot^2 \tfrac{1}{2}F = \frac{2r' - a}{a - g};$$

or, writing $2n$ for $\cot \frac{1}{2}F$ (Art. 18),

$$4n^2 = \frac{2r' - a}{a - g};$$

whence $r' = 2(a - g)n^2 + \frac{1}{2}a$ (1)

To find the distance KT, the similar triangles QPK and KST give

$$\frac{TK}{TS} = \frac{PK}{PQ};$$

whence

$$\frac{TK}{a - g} = \frac{PK}{g}$$

But PK = the lead of the turnout = L; hence, substituting this value and solving for TK, we obtain

$$TK = \frac{a - g}{g}L \qquad (2)$$

In applying this formula, the value of L will always be taken from Table II, Art. 23, even if point switches are inserted. This is because Table II gives the value of L on the supposition that QK and ME are arcs of circles, and they have been assumed circular in deriving formula 2 from Fig. 19.

EXAMPLE.—The distance between the center lines of two parallel, straight, standard-gauge tracks is 13 feet, and a No. 9 frog is used. To find the radius of the connecting curve and the distance KT, Fig. 19.

SOLUTION.—Since $a = 13$, $g = 4.708$, and $n = 9$, formula 1 gives

$$r' = 2 \times (13 - 4.708) \times 81 + \tfrac{13}{2} = 1{,}349.8 \text{ ft. Ans.}$$

To find KT, we have in formula 2, $a = 13$, $g = 4.708$, and from Table II, $L = 84.75$. Therefore,

$$KT = \left(\frac{13 - 4.708}{4.708}\right) \times 84.75 = 149.3 \text{ ft. Ans.}$$

EXAMPLE FOR PRACTICE

In the following problems, find r' and KT, if in each case $a = 13$ feet and $g = 4.708$ feet:

(*a*) When the frog number is 4.

(*b*) When the frog number is 10.

Ans. $\begin{cases} (a)\ r' = 271.8 \text{ ft.},\ KT = 66.35 \text{ ft.} \\ (b)\ r' = 1{,}664.9 \text{ ft.},\ KT = 165.9 \text{ ft.} \end{cases}$

---

31. Connecting Curve to the Outside Between Two Parallel Curved Tracks.—Let UN, Fig. 20, be the curved main track, and UE the turnout, which it is desired to connect with a parallel track DT'. Let $r = O_1E = O_1D$ be the radius of the connecting curve, and let $R = CB = CU$ be the radius of the main-track curve. Let the angle $SO_1K = m$, $SCK = M$, $CSK = Q$, and $CKS = P$.

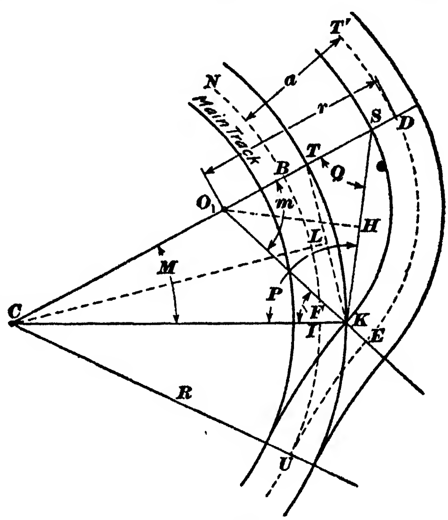


FIG. 20

The radius R of the main-track curve, the frog number n, and the distance a between the center lines of the parallel tracks must be known; the radius r and the distance KT from the point of frog to the point on the main line opposite to which the curve connects with the side track are to be computed.

1. *To Find the Radius of the Connecting Curve.*—The triangle CSK gives

$$\tan \tfrac{1}{2}(P - Q) = \frac{CS - CK}{CS + CK} \cot \tfrac{1}{2} M = \frac{CS - CK}{(CS + CK) \tan \tfrac{1}{2} M},$$

whence $$\tan \tfrac{1}{2} M = \frac{CS - CK}{CS + CK} \cot \tfrac{1}{2} (P - Q;$$

or, because $CS = R + a - \frac{1}{2}g$, and $CK = R + \frac{1}{2}g$,

$$\tan \tfrac{1}{2} M = \frac{a - g}{2R + a} \cot \tfrac{1}{2}(P - Q) \qquad (1)$$

Triangle $O_1 KS$ is isosceles, since $O_1 K = O_1 S = r - \frac{1}{2}g$; hence, the angles $O_1 SK$ and $O_1 KS$ are equal. Therefore, $Q = O_1 KS = P - F$; hence, $P - Q = P - (P - F) = F$. Substituting this value of $P - Q$ in the second member of equation (1),

$$\tan \tfrac{1}{2} M = \frac{a - g}{2R + a} \cot \tfrac{1}{2} F \qquad (1)$$

or, since $\cot \frac{1}{2} F = 2n$ (Art. **18**),

$$\tan \tfrac{1}{2} M = \frac{a - g}{2R + a} \times 2n \qquad (2)$$

By this formula, the value of M can be found when n, g, a, and R are given.

In the triangle $CO_1 K$ we have, since $\sin CO_1 K = \sin m$,

$$O_1 K = r - \tfrac{1}{2}g = \frac{CK}{\sin m} \sin M$$

But $CK = R + \frac{1}{2}g$, and m, being the exterior angle of the triangle, is equal to $F + M$. Hence, substituting these values,

$$r - \tfrac{1}{2}g = \frac{(R + \frac{1}{2}g) \sin M}{\sin (F + M)} \qquad (3)$$

To find r, the value of M must first be computed by formula **2**; formula **3** will then give the desired value of r.

2. *To Find the Distance KT.*—Drawing the chord KT, and CL perpendicular to this chord, the triangle CLT gives

$$LT = CT \sin TCL \qquad (2)$$

But $LT = \frac{1}{2}KT$, $CT = R + \frac{1}{2}g$, and $TCL = \frac{1}{2}M$. Therefore, substituting these values in (2),

$$\tfrac{1}{2}KT = (R + \tfrac{1}{2}g) \sin \tfrac{1}{2} M;$$

whence $$KT = 2(R + \tfrac{1}{2}g) \sin \tfrac{1}{2} M \qquad (4)$$

EXAMPLE.—If a siding is to be laid to the outside of a 4° main-track curve, using a No. 9 frog, what are the radius of the connecting curve and the distance KT, the distance between track centers being 13 feet?

SOLUTION.—In this example, $n = 9$, $a = 13$, and $g = 4.708$. The radius R corresponding to a 4° curve is 1,432.7 ft. Substituting these values in formula **2**,

$$\tan \tfrac{1}{2} M = \frac{2 \times 9 \times (13 - 4.708)}{2 \times 1{,}432.7 + 13};$$

whence $$M = 5° 56' 12''$$

By formula 2, Art. 18, or from Table I, $F = 6° 21' 35''$. Therefore, substituting the values of M and F in formula 3,

$$r - 2.35 = \frac{(1{,}432.7 + 2.35) \sin 5° 56' 12''}{\sin (6° 21' 35'' + 5° 56' 12'')};$$

whence $r = 699.32$ ft. Ans.

Formula 4 gives

$$KT = 2 \times (1{,}432.7 + 2.35) \sin \tfrac{1}{2} (5° 56' 12'') = 148.62 \text{ ft. Ans.}$$

EXAMPLE FOR PRACTICE

In the following problems, find the radius r of the connecting curve, and the distance KT, if the distance a between the track centers is 13 feet, and the gauge is 4.708 feet.

(*a*) $R = 819.02$, $n = 5.5$.

(*b*) The degree of the main-track curve is 8°, and the frog number is 7.

Ans. $\begin{cases} (a) \; M = 6° 19' 28'', r = 316.97 \text{ ft.}, KT = 90.62 \text{ ft.} \\ (b) \; M = 9° 10' 36'', r = 386.99 \text{ ft.}, KT = 115.05 \text{ ft.} \end{cases}$

---

32. Connecting Curve to the Inside Between Two Parallel Curved Tracks.—In Figs. 21 and 22, let UB be the main track, UH the turnout, and HD the connecting curve. Let O_1 be the center of the connecting curve, and C the center of the main-line curve. Then, two cases may occur, according as O_1 and C lie on opposite sides of the chord KT, as in Fig. 21, or on the same side, as in Fig. 22.

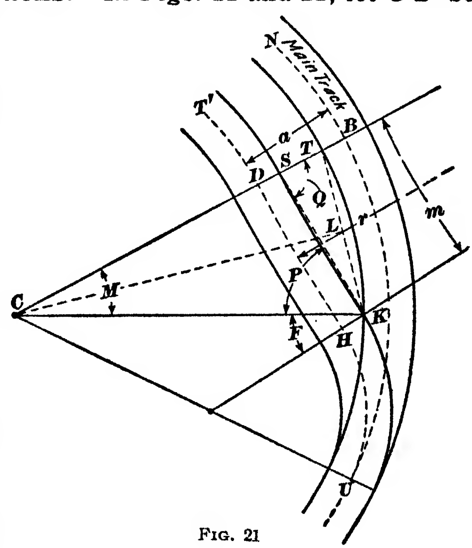


FIG. 21

In either Fig. 21 or Fig. 22, let $M = SCK$ be the angle at the center of the main curve subtended by the connecting curve, and let $m = SO_1K$ be the central angle of the connecting curve.

In the first case, Fig. 21, the triangle $C K O_1$ gives

$$F = M + m \qquad (1)$$

and, $$M = F - m;$$

hence, M is less than F.

In the second case, Fig. 22, the triangle $C K O_1$ gives

$$M = F + m; \qquad (2)$$

hence, M is greater than F.

When the angle M has been computed, it is compared with the frog angle F; if M is less than F, the connecting curve

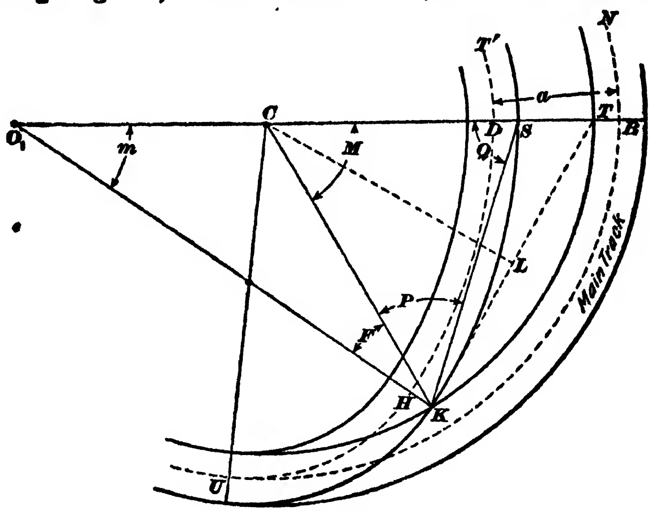


FIG. 22

will be as shown in Fig. 21; if M is greater than F, the curve will be as shown in Fig. 22.

33. In either figure, let the angle $O_1 S K = Q$, and $C K S = P$. In the triangle $S C K$, Fig. 21,

$$\frac{CK - CS}{CK + CS} = \frac{\tan \frac{1}{2}(180° - Q - P)}{\tan \frac{1}{2}(180° - Q + P)} \qquad (1)$$

But, since Q is the exterior angle of the triangle, it is equal to $P + M$; hence, $\frac{1}{2}(180° - Q + P) = 90° - \frac{1}{2}M$. Since the triangle $S O_1 K$ is isosceles, $O_1 K S = O_1 S K = Q$. Hence, at the point K, $P + Q + F = 180°$; consequently, $180° - P - Q = F$. Substituting these values in equation (1), there results

$$\frac{\tan\frac{1}{2}(180° - Q - P)}{\tan\frac{1}{2}(180° - Q + P)} = \frac{\tan\frac{1}{2}F}{\cot\frac{1}{2}M} = \frac{CK - CS}{CK + CS} \qquad (2)$$

Similarly, in the triangle SCK, Fig. 22,

$$\frac{CK - CS}{CK + CS} = \frac{\tan\frac{1}{2}(Q - P)}{\tan\frac{1}{2}(Q + P)} \qquad (3)$$

But the angle KST is equal to $180° - Q$, and it also equals $M + P$, since it is exterior to the triangle; therefore, $180° - Q = M + P$, $Q + P = 180° - M$, and

$$\tfrac{1}{2}(Q + P) = \tfrac{1}{2}(180° - M) = 90° - \tfrac{1}{2}M$$

Since the triangle O_1KS is isosceles, the angle $O_1KS = O_1SK$, or $F + P = Q$. Hence, $Q - P = F$. Substituting these values in equation (3),

$$\frac{\tan\frac{1}{2}(Q - P)}{\tan\frac{1}{2}(Q + P)} = \frac{\tan\frac{1}{2}F}{\tan(90° - \frac{1}{2}M)}$$

$$= \frac{\tan\frac{1}{2}F}{\cot\frac{1}{2}M} = \frac{CK - CS}{CK + CS} \qquad (4)$$

By comparing equations (2) and (4), it is seen that, in either figure,

$$\frac{\tan\frac{1}{2}F}{\cot\frac{1}{2}M} = \frac{CK - CS}{CK + CS}$$

But in either figure, $CK = R - \frac{1}{2}g$, and $CS = R - a + \frac{1}{2}g$. Hence, substituting these values,

$$\frac{\tan\frac{1}{2}F}{\cot\frac{1}{2}M} = \frac{a - g}{2R - a};$$

whence
$$\tan\tfrac{1}{2}M = \frac{a - g}{2R - a}\cot\tfrac{1}{2}F, \qquad (1)$$

or, writing $2n$ for $\cot\frac{1}{2}F$,

$$\tan\tfrac{1}{2}M = \frac{2n(a - g)}{2R - a} \qquad (2)$$

These formulas will give the value of M in either case. If M is less than F, the location will be as in Fig. 21; if M is greater than F, the location will be that shown in Fig. 22.

34. Case I.—*Center of the connecting curve on the outside of the main-track curve; M less than F, Fig. 21. It is desired to find $r = O_1D$, and the distance KT.*—In the triangle O_1KC, Fig. 21,

$$\frac{O_1K}{CK} = \frac{\sin M}{\sin CO_1K}$$

But $O_1K = r - \frac{1}{2}g$, $CK = R - \frac{1}{2}g$, and, from equation (1), Art. **32**, $CO_1K = m = F - M$. Therefore, substituting these values in the above equation, and solving for $r - \frac{1}{2}g$, the following formula is obtained:

$$r - \tfrac{1}{2}g = \frac{\sin M}{\sin (F - M)}(R - \tfrac{1}{2}g) \qquad (1)$$

Drawing the chord KT and the perpendicular CL to this chord, the triangle CLT gives

$$TL = CT \sin TCL;$$

or, because $TL = \frac{1}{2}KT$, $CT = R - \frac{1}{2}g$, and $TCL = \frac{1}{2}M$,

$$KT = 2(R - \tfrac{1}{2}g) \sin \tfrac{1}{2}M \qquad (2)$$

EXAMPLE.—A siding is to be laid on the inside of a 4° main-track curve, using a No. 9 frog, the distance between the track centers being 13 feet. To find the radius of the connecting curve and the distance KT, Fig. 21.

SOLUTION.—Since $a = 13$, $n = 9$, $g = 4.708$, and $R = 1{,}432.7$ (the radius corresponding to a 4° curve), formula **2**, Art. **33**, gives

$$\tan \tfrac{1}{2}M = \frac{2 \times 9(13.0 - 4.708)}{2 \times 1{,}432.7 - 13.0};$$

whence $\frac{1}{2}M = 2° 59' 43''$; $M = 5° 59' 26''$

From formula **2**, Art. **18**, or from Table I, F, for a No. 9 frog, is found to be 6° 21′ 35″. Since the value found for M is less than this value of F, the location falls under Case I.

From formula **1**,

$$r - 2.35 = \frac{\sin 5° 59' 26''}{\sin (6° 21' 35'' - 5° 59' 26'')} \times (1{,}432.7 - 2.35);$$

whence $r = 23{,}171$ ft. Ans.

This shows that the connecting curve will be very nearly straight, the degree of curve being 0° 15′. Substituting these values in formula **2**,

$$KT = 2 \times (1{,}432.7 - 2.35) \sin 2° 59' 43'' = 149.48 \text{ ft. Ans.}$$

35. Case II.—*Center of the connecting curve on the inside of the main-track curve; M greater than F, Fig. 22. It is desired to find $r = O_1D$ and the distance KT.*—In the triangle O_1CK, Fig. 22,

$$\frac{O_1K}{CK} = \frac{\sin O_1CK}{\sin CO_1K}$$

But $O_1K = r + \frac{1}{2}g$, $CK = R - \frac{1}{2}g$, $O_1CK = 180° - M$; hence, $\sin O_1CK = \sin M$. Also, $CO_1K = m = M - F$,

from equation (2), Art. **32.** Substituting these values in the preceding equation and solving for $r + \frac{1}{2}g$,

$$r + \tfrac{1}{2}g = (R - \tfrac{1}{2}g)\frac{\sin M}{\sin (M - F)} \qquad \textbf{(1)}$$

We have, also, exactly as in Case I,

$$TL = CT \sin \tfrac{1}{2}M$$

and

$$KT = 2(R - \tfrac{1}{2}g) \sin \tfrac{1}{2}M \qquad \textbf{(2)}$$

EXAMPLE.—A siding is to be laid on the inside of a 6° main-track curve using a No. 10 frog, the distance between the center lines of the parallel tracks being 14.5 feet. To find the radius of the connecting curve and the distance KT.

SOLUTION.—For the 6° curve, $R = 955.37$ ft. Substituting the values in formula **2**, Art. **33**,

$$\tan \tfrac{1}{2}M = \frac{2 \times 10(14.5 - 4.708)}{2 \times 955.37 - 14.5};$$

whence $\frac{1}{2}M = 5° 53' 47''$; $M = 11° 47' 34''$

From formula **2**, Art. **18**, or from Table I, F is found to be $5° 43' 29''$. Therefore, M is greater than F, and the location falls under Case II. By formula **1**,

$$r + 2.35 = (955.37 - 2.35)\frac{\sin 11° 47' 34''}{\sin (11° 47' 34'' - 5° 43' 29'')};$$

whence $r = 1{,}840.2$ ft. Ans.

The degree of the connecting curve will therefore be 3° 7′. From formula **2**,

$$KT = 2 \times (955.37 - 2.35) \sin 5° 53' 47'';$$

whence $KT = 195.80$ ft. Ans.

EXAMPLE FOR PRACTICE

In the following problems, where a siding is to be laid to the inside of the main-track curve, find the radius of the connecting curve and the distance KT, the distance between the center lines of the parallel curved tracks being 13 feet.

(*a*) Degree of main-track curve = 3° 20′, frog number = 10.5.

(*b*) Degree of main-track curve = 8°, frog number = 4.5.

Ans. $\begin{cases} (a)\ M = 5° 49' 14'',\ r = 27{,}102 \text{ ft.},\ KT = 174.33 \text{ ft. (Case II)} \\ (b)\ M = 6° 0' 52'',\ r = 647.22 \text{ ft.},\ KT = 74.96 \text{ ft. (Case I)} \end{cases}$

CROSS-OVERS

36. A **cross-over** is a stretch of track that connects two parallel tracks, and enables a train to pass from one track to the other. Thus, in Fig. 23, if UV and $U'V'$ are two parallel tracks, the track RZR' is a cross-over.

The cross-over shown in Fig. 23 consists of two equal turnouts Rm and $R'm'$, whose frog angles at K and K' are

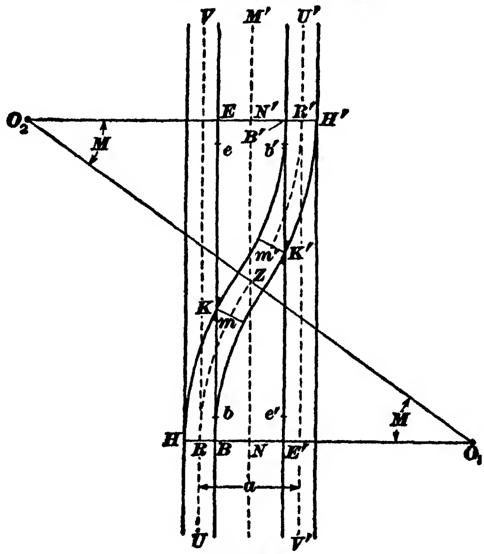


FIG. 23

equal, and a reversed curve mZm' connecting the ends of these turnouts, Z being the point of reversal.

The two halves RZ and $R'Z$ of the cross-over are equal in all their parts; if Fig. 23 is held upside down or inverted, the figure will not be changed; the two equal turnouts will have merely changed places.

37. Cross-Over Between Two Parallel Straight Tracks.—Let H, B, H', and B', Fig. 23, be the heels of switch, O_1 and O_2 the centers of the turnout curves, and $r = O_1Z = O_2Z$ the radius to these curves. To lay out the cross-over, it is necessary to compute the distances $BE = B'E'$, the

central angle $R O_1 Z = R' O_2 Z = M$, and the radius r of the reversed curve, which is also the radius of the turnout curves.

When the frog angle has been chosen, the lead $B K = B' K'$ and the radius r are obtained by formulas **2** and **4**, Art. **21**, or are taken from Table II.

To find M, the triangle $O_1 N Z$ gives

$$\cos M = \frac{O_1 N}{O_1 Z} = \frac{r - \frac{1}{2} a}{r} = 1 - \frac{a}{2 r}$$

Therefore,

$$\sin^2 M = 1 - \cos^2 M = 1 - \left(1 - \frac{a}{2 r}\right)^2 = \frac{a}{r} - \frac{a^2}{4 r^2}$$

and $$\sin M = \sqrt{\frac{a}{r}\left(1 - \frac{a}{4 r}\right)} \qquad (1)$$

Unless the tracks are at least 30 feet apart, the small fraction $\frac{a}{4 r}$ may be dropped, and we may write

$$\sin M = \sqrt{\frac{a}{r}} \qquad (2)$$

To find the distance $B E = B' E'$, we have

$$B E = N N' = 2 N Z = 2 r \sin M;$$

or, substituting the value of sin M from formula **2**,

$$B E = B' E' = 2 r \sqrt{\frac{a}{r}} = 2 \sqrt{a r} \qquad (3)$$

38. Since, in Fig. 23, the turnout rails $H K$ and $H' K'$ are uniformly curved, the preceding equations will only apply to stub switches. To apply them to point switches, proceed as follows: Having located one frog point K of the point-switch turnout, measure back from K the lead $K B$ for a stub-switch turnout taken from Table II, and from the point R of the center line opposite B run in the curve $R m Z$ to the point of reversal. Then, measure off the distance $B E$ computed by formula **3** of the preceding article, and from the point B' opposite to E lay off the stub-switch lead $B' K'$ to locate the second point of frog K'. Then run in the center-line curve $R' Z$. The two frog points and the reversed curve $m Z m'$ are thus located. Finally, measure back from

K and K' the distances $Kb = K'b'$ = the point-switch lead from Table III, to locate the toes of the point switches at b and b', and complete the location of these switches as explained in Art. **52.**

It is evident that the whole length of the cross-over when point switches are employed is $be = b'e' = BE - 2 \times Bb = 2\sqrt{ar} - 2 \times Bb$. Therefore,

$$be = b'e' = 2\sqrt{ar} - 2 \times (\text{lead of stub switch} - \text{lead of point switch})$$

A stake is usually driven at Z, midway between the inner rails and midway between the points N and N', and the turn-out curves are continued to this point. This is more accurate than to attempt to determine the point of reversal by the use of the central angle M.

EXAMPLE 1.—If the center lines of the straight tracks are 13 feet apart, and No. 9 frogs are employed, what are the dimensions of the cross-over for a stub switch?

SOLUTION.—From Table II,

lead $BK = B'K'$ = 84.75 ft. Ans.

Radius = r = 762.75 ft. Ans.

Therefore, by formula **2**, Art. **37**,

$$\sin M = \sqrt{\frac{13}{762.75}}; \text{ whence } M = 7° 30' 5''. \text{ Ans.}$$

By formula **3**, Art. **37**,

$$BE = B'E' = 2\sqrt{13 \times 762.75} = 199.16 \text{ ft. Ans.}$$

EXAMPLE 2.—To make the necessary modifications of the preceding solution if point switches are to be inserted.

SOLUTION.—The radius r will be the same, and the center line of the reversed curve $m Z m'$ will occupy the same position, as before. The lead Kb will, however, be different. From Table III, Kb = 72.20 ft. Then,

$$Bb = 84.75 - 72.20 = 12.55 \text{ ft.}$$

As found above, BE = 199.16. Therefore,

$$be = b'e' = 199.16 - 2 \times 12.55 = 174.06 \text{ ft. Ans.}$$

EXAMPLES FOR PRACTICE

1. Solve example 1 of Art. **38**, if a No. 6 frog is employed.

Ans. $\begin{cases} BK = 56.50,\ r = 339,\ M = 11° 18' 35'', \\ \text{and } BE = 132.77 \text{ ft.} \end{cases}$

2. Find the whole length of the preceding cross-over if point switches are employed. Ans. $be = b'e'$ = 131.77 ft.

39. Another Form of Cross-Over Between Two Parallel Straight Tracks.—A second form of cross-over is shown in Fig. 24. In this form, the ends of the two equal turnouts are connected by a straight track $KTK'T'$. The cross-over with a reversed curve, Fig. 23, is much shorter than this straight-track cross-over, and thus requires less length of track and occupies less room. The straight-track form is, however, to be preferred, it being less wearing on the rolling stock; for it gives the wheel trucks a better opportunity to adjust themselves to the reversion of curvature.

In order to lay out a straight-track cross-over, it is only necessary to compute the distance $BE = B'E'$, Fig. 24, in addition to the usual dimensions of the two turnouts. The turnout Rm having been put in place, the distance BE is laid off and the heels B' and H' of the second turnout are located opposite the point E. This turnout is then laid out as far as m', and finally the straight rails KT' and $K'T$ are laid joining the ends of the two turnouts.

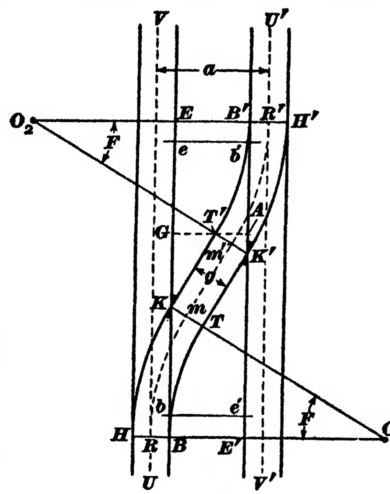


FIG. 24

As in Art. **38**, the only modification of the work for a point switch arises from the fact that the lead $Kb = K'b'$ of the point switch is less than that of the stub switch. The whole length of cross-over is, as in Art. **38**,

$$be = BE - 2 \times (\text{stub-switch lead} - \text{point-switch lead})$$

40. To Find the Distance $BE = B'E'$.—Fig. 24 gives

$$BE = BK + KG + GE$$

but

$$KG = KT' \cos F, \text{ and } GE = AB' = B'K' - AK';$$

therefore,

$$BE = BK + B'K' + KT' \cos F - AK' \qquad (1)$$

Now, $BK = B'K' =$ the lead L; and in the triangle $K'T'A$, $T'K' =$ the gauge g, and $AT'K' = F$. We have in this triangle, $AK' = T'K' \sin AT'K' = g \sin F$. Substituting these values in equation (1),

$$BE = 2L + KT' \cos F - g \sin F \qquad (2)$$

Also,

$$KT' = \frac{GT'}{\sin GKT'} = \frac{GA - AT'}{\sin F} = \frac{(a-g) - AT'}{\sin F}$$

$$= \frac{(a-g) - T'K' \cos AT'K'}{\sin F} = \frac{a - g - g \cos F}{\sin F}$$

Substituting this value in equation (2),

$$BE = 2L + \frac{(a - g - g \cos F) \cos F}{\sin F} - g \sin F$$

$$= 2L + \frac{(a-g) \cos F - g \cos^2 F - g \sin^2 F}{\sin F}$$

$$= 2L + \frac{(a-g) \cos F - g(\sin^2 F + \cos^2 F)}{\sin F};$$

or, since $\sin^2 F + \cos^2 F = 1$,

$$BE = 2L + \frac{(a-g) \cos F - g}{\sin F} \qquad (1)$$

By a series of trigonometric transformations, this formula may be reduced to the form

$$BE = 2L + \frac{(a - 2g) \cot^2 \frac{1}{2} F - a}{2 \cot \frac{1}{2} F};$$

or, writing $2n$ instead of $\cot \frac{1}{2} F$,

$$BE = 2L + \frac{4(a-2g)n^2 - a}{4n} = 2L - \frac{a}{4n} + (a - 2g)n \qquad (2)$$

The frog number having been selected, the value of L is taken from Table II; formula **2** will then give the required distance for a stub switch.

41. If a point switch is employed, we have, from Art. **39**,

$$be = BE - 2(L - L') = BE - 2L + 2L'$$

in which L' is the lead of the point switch taken from Table III. Substituting the value of BE from formula **2**, Art. **40**, we obtain

$$be = 2L' - \frac{a}{4n} + (a - 2g)n$$

This formula will give the whole length of cross-over when a point switch is employed.

42. The standard value of a for double-track work is 13 feet. It is evident that the greater the frog angle, the less will be the length of the cross-over. Usually, a No. 8 or a No. 9 frog will be used for the standard cross-over, and this will give a length of 160 to 200 feet. Frequently, however, much shorter cross-overs must be selected, especially in yard work. The engineer should compute two short tables, one by formula **2**, Art. **40**, and the other by the formula of Art. **41**, giving the various lengths of cross-over for the different frogs that he will employ. The selection of the best cross-over for any particular case can then be very quickly and easily made.

EXAMPLE.—If the center lines of the parallel tracks are 13 feet apart, and No. 9 frogs are employed, what is the distance BE of a straight cross-over for a stub switch?

SOLUTION.—Here, $n = 9$, $a = 13$, $g = 4.708$. From Table II, $L = 84.75$ ft. Substituting these values in formula **2**, Art. **40**,

$$BE = 2 \times 84.75 - \frac{13}{4 \times 9} + (13 - 2 \times 4.708)\,9 = 201.40 \text{ ft.} \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE

1. In the following problems, find the length BE of cross-over if the distance between the center lines of the parallel straight tracks is 13 feet, the gauge 4.708 feet, and point switches are used.

(a) The frog number is 8.
(b) The frog number is 6.5.

Ans. (a) 162.35 ft. (b) 140.48 ft.

2. In the following problems, if $a = 13$ feet, $g = 4.708$ feet, and stub switches are employed, what is the length BE of the cross-over?

(a) The frog number is 8.
(b) The frog number is 6.5.

Ans. (a) 178.93 ft. (b) 145.22 ft.

---

43. Cross-Over Between Two Parallel Curved Tracks.—Let HV and $H'V'$, Fig. 25, be the two parallel curved tracks, the distance between whose center lines is a, and whose common center is at C. Let R be the radius of

the inner track, so that $R = CH = CV$; the radius of the outer track is then $R + a$. The cross-over will consist of two turnouts J_1H_1 and J_2H_2, and a reversed curve H_1ZH_2 connecting these turnouts, the point of reversal being at Z.

The first turnout J_1H_1 is a turnout to the inside of the curved track J_1V'. Let O_1 be the center of the turnout curve; denote the radius $O_1J_1 = O_1H_1$ by r_1, the angle K_1CJ_1 by M_1, and the number of the frog at K_1 by n_1.

The second turnout J_2H_2 is a turnout to the outside of the

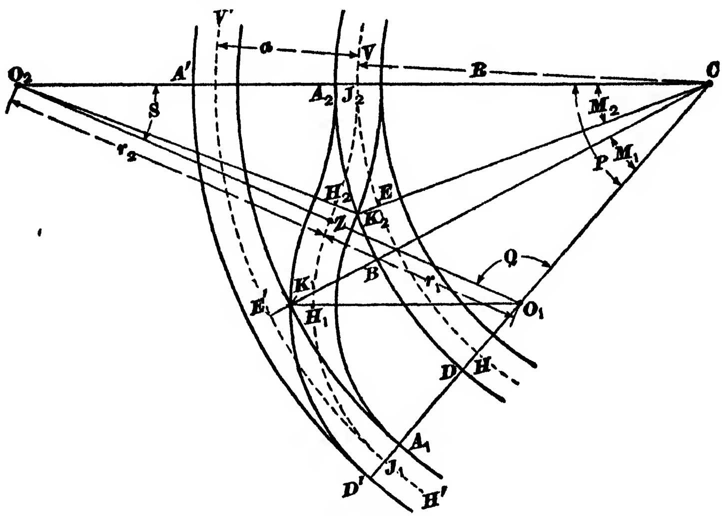


FIG. 25

curved track VH. Let O_2 be the center of this turnout curve; denote the radius $O_2J_2 = O_2H_2$ by r_2, the angle K_2CJ_2 by M_2, and the number of the frog at K_2 by n_2.

When the frog numbers have been selected, the first step in the computation of the dimensions of the cross-over is to determine the lead A_1K_1 of the first turnout and the radius r_1 by Art. **29**, and also the lead A_2K_2 of the second turnout and the radius r_2 by Art. **26**. The next step is to compute the whole central angle $A'CD' = P$ of the cross-over, and the central angle K_1CK_2 between the two frogs. Finally, the distances J_1Z and J_2Z from the heels of switch to the point of reversal must be found.

44. To Compute the Central Angle $A'CD'$.—In the triangle CO_1O_2, the three sides are known; from these the three angles may be computed. We have

$$CO_2 = CJ_2 + O_2J_2 = R + r_2$$
$$CO_1 = CJ_1 - O_1J_1 = R + a - r_1$$
$$O_1O_2 = O_2Z + O_1Z = r_1 + r_2$$

From trigonometry, if a, b, and c are the three sides of a triangle, and A, B, and C are the three angles of the triangle opposite, respectively, to these three sides, then A, B, and C can be computed by the formulas

$$\left.\begin{aligned} \tan \tfrac{1}{2} A &= \sqrt{\frac{(s-b)(s-c)}{s(s-a)}} \\ \tan \tfrac{1}{2} B &= \sqrt{\frac{(s-a)(s-c)}{s(s-b)}} \\ \tan \tfrac{1}{2} C &= \sqrt{\frac{(s-a)(s-b)}{s(s-c)}} \end{aligned}\right\} \qquad (1)$$

in which $s = \frac{1}{2}(a + b + c)$.

To apply these equations to the triangle O_1O_2C, let

$$a = CO_2 = R + r_2, \qquad A = CO_1O_2 = Q$$
$$b = CO_1 = R + a - r_1, \qquad B = CO_2O_1 = S$$
$$c = O_1O_2 = r_1 + r_2, \qquad C = O_1CO_2 = A'CD' = P$$

Then, $s = R + r_2 + \frac{1}{2} a$, $s - a = \frac{1}{2} a$, $s - b = r_1 + r_2 - \frac{1}{2} a$, $s - c = R - r_1 + \frac{1}{2} a$, and

$$\tan \tfrac{1}{2} P = \tan \tfrac{1}{2} C = \sqrt{\frac{\frac{1}{2} a (r_1 + r_2 - \frac{1}{2} a)}{(R + r_2 + \frac{1}{2} a)(R - r_1 + \frac{1}{2} a)}} \qquad (1)$$

$$\tan \tfrac{1}{2} S = \tan \tfrac{1}{2} B = \sqrt{\frac{\frac{1}{2} a (R - r_1 + \frac{1}{2} a)}{(R + r_2 + \frac{1}{2} a)(r_1 + r_2 - \frac{1}{2} a)}} \qquad (2)$$

$$\tan \tfrac{1}{2} Q = \tan \tfrac{1}{2} A = \sqrt{\frac{(R - r_1 + \frac{1}{2} a)(r_1 + r_2 - \frac{1}{2} a)}{(R + r_2 + \frac{1}{2} a)\frac{1}{2} a}} \qquad (3)$$

45. To Find the Angle K_2CK_1 Between the Two Points of Frog.—If D' is the degree of curve of $H'V'$, then (see *Circular Curves*),

$$M_1 = J_1E' \times \frac{D'}{100}$$

The lead $L_1 = A_1K_1$ may be used without sensible error for J_1E'; this gives

$$M_1 = L_1 \times \frac{D'}{100} \qquad (1)$$

Similarly, if D is the degree of curve of HV, and L_2 the lead A_2K_2,

$$M_2 = L_2 \times \frac{D}{100} \qquad (2)$$

From the figure,

$$K_2CK_1 = P - M_1 - M_2 \qquad (3)$$

When P has been found by formula **1** of the preceding article, and M_1 and M_2 by formulas **1** and **2** of this article, formula **3** will give the value of K_2CK_1.

46. To Find the Distances J_1Z and J_2Z from the Points of Switch to the Point of Reversal.—If d_1 is the degree of curve of J_1Z, and d_2 that of J_2Z, then (see *Circular Curves*),

$$J_1Z = \frac{ZO_1D'}{d_1} \times 100 = \frac{180° - Q}{d_1} \times 100 \qquad (1)$$

$$J_2Z = \frac{S}{d_2} \times 100 \qquad (2)$$

These formulas will give the distances J_1Z and J_2Z when the angles Q and S have been found by formulas **2** and **3**, Art. **44**.

47. It will be seen that the computation of the dimensions of the cross-over is a long one. It is further complicated by the fact that the frog numbers n_1 and n_2 must be so chosen that the point of reversal Z will fall between the points H_1 and H_2. Thus, if the second turnout curve J_2H_2 were made much sharper than shown in Fig. 25—that is, if the frog angle at K_2 were much increased—the theoretical point of reversal Z would fall inside of the turnout J_2H_2, and the location would not be possible.

If correct frog numbers have been assumed, the value of J_1Z computed by formula **1**, Art. **46**, will be greater than the lead L_1, and J_2Z will be greater than L_2. To guide the student in selecting the frogs, it may be said that, if the frog numbers are equal, the solution will always be possible; if the outer frog number is greater by 1 than the inner, it will nearly always be possible; as the outer frog number is increased, Z will approach more and more closely to H_2;

a difference of more than 2 between the frog numbers is rarely possible unless the curvature of the main track is very slight. Similarly, increasing n_2 causes Z to approach H_1, and n_2 can seldom exceed n_1 by more than 2.

In practice, a cross-over of this kind is located as if both of the switches were stub switches, r_1, r_2, L_1, and L_2 being taken from Table II. After the frogs have been placed in position and the center line $H_2 Z H_1$ has been laid out, the heels of the switch are located by Table III, if a point switch is employed.

EXAMPLE.—If $R = 1{,}267.1$, $a = 13$, $n_1 = 9$, and $n_2 = 7$, what are the dimensions of the cross-over?

SOLUTION.—Since $R = 1{,}267.1$ ft., $D = 4° 31'$. Since $a = 13$, the radius of $H' V'$ is $R + a = 1{,}267.1 + 13 = 1{,}280.1$, and, therefore, $D' = 4° 29'$.

For the first turnout, from Table II, $L_1 = 84.75$. By Art. 29, $d_1 = 4° 29' + 7° 31' = 12°$. Therefore, $r_1 = 478.34$ ft.

For the second turnout, from Table II, $L_2 = 65.92$. By Art. 28, $d_2 = 12° 26' - 4° 31' = 7° 55'$. Therefore, $r_2 = 724.31$ ft.

1. To compute the angles P, S, Q, we have,

$$\tfrac{1}{2}\, a = 6.5 \text{ ft.}$$

$$r_1 + r_2 - \tfrac{1}{2}\, a = 478.34 + 724.31 - 6.5 = 1{,}196.2$$

$$R + r_2 + \tfrac{1}{2}\, a = 1{,}267.1 + 724.31 + 6.5 = 1{,}997.9$$

$$R - r_1 + \tfrac{1}{2}\, a = 1{,}267.1 - 478.34 + 6.5 = 795.26$$

Therefore, substituting these values in formulas 1, 2, and 3, Art. 44,

$$\tan \tfrac{1}{2} P = \sqrt{\frac{6.5 \times 1{,}196.2}{1{,}997.9 \times 795.26}}; \text{ whence } P = 8° \; 0' \; 10''$$

$$\tan \tfrac{1}{2} S = \sqrt{\frac{6.5 \times 795.26}{1{,}196.2 \times 1{,}997.9}}; \text{ whence } S = 5° \; 19' \; 32''$$

$$\tan \tfrac{1}{2} Q = \sqrt{\frac{795.26 \times 1{,}196.2}{1{,}997.9 \times 6.5}}; \text{ whence } Q = \underline{166° \; 40' \; 18''}$$

Check: sum $= 180° \; 0' \; 0''$

2. To compute the angle $K_2 C K_1$, we have, from Art. 45,

$$M_1 = \frac{L_1}{100} \times D' = \frac{84.75}{100} \times 4° \, 29' = 3° \, 47' \, 59''$$

$$M_2 = \frac{L_2}{100} \times D = \frac{65.92}{100} \times 4° \, 31' = 2° \, 58' \, 39''$$

Substituting these values in formula 3, Art. 45, and also the value of P just found,

$$K_2 C K_1 = 8° \, 0' \, 10'' - 3° \, 47' \, 59'' - 2° \, 58' \, 39'' = 1° \, 13' \, 32''$$

3. To compute the distances $J_1 Z$ and $J_2 Z$, we have, by formulas **1** and **2**, Art. **46**,

$$J_1 Z = \frac{180° - Q}{d_1} \times 100 = \frac{180° - 166° \, 40' \, 18''}{12° \, 0'} \times 100 = 111.07 \text{ ft.}$$

$$J_2 Z = \frac{S}{d_2} \times 100 = \frac{5° \, 19' \, 32''}{7° \, 55'} \times 100 = 67.27 \text{ ft.}$$

Since $J_1 Z = 111.07$ ft. and $J_1 H_1 = 84.75$ ft., the point Z is beyond H_1. Since $J_2 H_2 = 65.92$ ft. and $J_2 Z = 67.27$ ft., the point of reversal Z is only 1.35 ft. beyond H_2.

The selection $n_1 = 9$ and $n_2 = 7$ is, therefore, admissible. If n_1 were, however, but very slightly increased, the location would not be possible.

LADDER TRACKS

48. When a series of turnouts connect a straight main track with a number of parallel equally distant side tracks, the whole arrangement of tracks is called a **ladder track.** Ladder tracks are very commonly employed in yards, where they are most useful. A convenient arrangement of the turnouts is shown in Fig. 26.

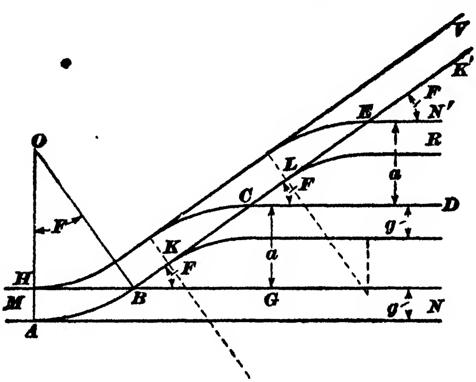


FIG. 26

If MN is the main track, the side track MV is first run off at an angle $KBG = F$ with MN. At equal distances along MV, the sidings are run off so as to make the angles $LCD = K'EN' = F$ with the side track. All the sidings will thus be parallel to the main track MN.

The rails BK, CD, and EN' are straight beyond the frog points, and the three frogs shown are all equal; the leads HB, KC, and LE are therefore equal, and to lay out the track it is only necessary to compute the dimensions of one turnout and also the distances BC and CE between the successive points of frog.

If a is the distance between the center lines of the parallel tracks, we have

$$BC = \frac{a}{\sin F} \qquad (1)$$

By writing $2 \sin \frac{1}{2} F \cos \frac{1}{2} F$ instead of $\sin F$, then expressing both $\sin \frac{1}{2} F$ and $\cos \frac{1}{2} F$ in terms of $\cot \frac{1}{2} F$, and writing $2n$ instead of $\cot \frac{1}{2} F$, formula 1 can be reduced to the form

$$BC = a\left(n + \frac{1}{4n}\right) \qquad (2)$$

The distance BK may be found by the formula

$$BK = BC - \text{lead } KC \qquad (3)$$

EXAMPLE.—If $a = 12.8$ feet and $n = 8$, to find BC and BK for a stub switch.

SOLUTION.—By formula 2,

$$BC = 12.8\left(8 + \tfrac{1}{32}\right) = 102.8 \text{ ft. Ans.}$$

From Table II, the lead $= KC = 75.33$ ft.; therefore, by formula 3,

$$BK = 102.8 - 75.3 = 27.5 \text{ ft. Ans.}$$

LAYING OUT TURNOUTS

49. Location of Turnouts.—If a stub switch is to be inserted, the toe A, Fig. 1, should, if possible, be located at a rail joint of the existing track. This will avoid one cutting of the main rail and insure a complete rail length AE back of the toe, giving a sufficient length of rail BE back of the heel to be spiked firmly to the ties. The opposite rail must usually be cut at D, and also back of D at a point G to allow the insertion of a single rail DG.

If the lead BK, taken from Table II, brings either end a or b of the frog rail at a joint in the main track, a second rail cutting will be avoided. In practice, stub switches are not inserted in first-class work, and it is always permissible to increase or diminish the lead AK as much as 5 per cent. to bring the ends a or b to a rail joint.

50. If a point switch is to be inserted, the upper end b, Fig. 3, of the frog rail is located at a rail joint; the inner rail must then be cut at a and B, but this is the only cutting necessary. If, when this is done, the lead $A'K$ taken from Table III brings the ends A or D of the switch rails near a

joint of the old track, the bolts and angle splices at this joint will prevent the switch from being thrown. This is evident from Fig. 5. If it is not desired to insert a frog having a different lead, the whole turnout must be moved backwards or forwards until the toe of the switch clears the joint, and the effort to avoid one cutting of the rail must be abandoned.

If the rail lengths are uniformly 30 feet, the maximum shift of frog to find a rail joint will be 15 feet. Usually, there is no objection to this shifting, but, if the position of the turnout is exactly fixed, which sometimes occurs when there is but a limited space available for the track, no rail cuttings can be avoided, and, if necessary, a part of the old track must be taken up and relaid to bring the rail joints clear of the switch points.

51. To Lay Out a Stub Switch.—Having decided on the position of the end b, Fig. 1, of the frog rail, measure the total length of the frog and deduct it from the length of the rail to be cut, marking with red chalk on the flange of the rail the point at which the rail is to be cut. From the definition of n, we have, in Fig. 9,

$$n = \frac{c\,h}{a\,b}$$

and hence $c\,h = n \times a\,b$. To calculate the distance from the heel to the theoretical point of frog, the width of the frog at the heel is measured and multiplied by the frog number. For example, if the width of the frog at the heel is $8\frac{1}{2}$ inches, and a No. 8 frog is to be used, the theoretical distance from the heel to the point of frog is $8.5 \times 8 = 68$ inches $= 5$ feet 8 inches. Measure off this distance from the point marking the heel of the frog; this will locate the point of frog, which should be distinctly marked with red chalk on the flange of the rail. It is a common practice to make a distinct mark on the web of the main-track rail, directly opposite to the point of frog. This point being under the head of the rail, it is protected from wear and the weather. The heel of the turnout is then located by measuring back the lead from the point of frog. Next, make a chalk mark on both main-track

rails on a line marking the center of the head-block. A more permanent mark is made with a center punch. Stretch a cord touching these marks, and drive a stake on each side of the track, with a tack in each. This line should be at right angles to the center line of the track, and the stakes should be sufficiently far from the track not to be disturbed when putting in switch ties. Next, cut the switch ties to proper length; draw the spikes from the track ties, three or four at a time, and remove the ties from the track, replacing them with switch ties, and tamping the latter securely in place. When all the long ties are tamped, cut the main-track rail for the frog, being careful that the amount cut off is just equal to the length of the frog. If, by increasing or decreasing the length of the lead 5 per cent., the cutting of a rail can be avoided, this should be done, especially for frogs above No. 8.

Full-length rails (30-feet) should be used for moving or switch rails, and care should be taken to leave a joint of proper width at the head-chair. The head-chairs should be spiked to the head-block so that the main-track rails will be in perfect line. From 8 to 10 feet of the switch rails should be spiked to the ties. The tie-rods are placed between the switch ties, which should not be more than 15 inches from center to center of tie. The connection-rod should be attached to the head-rod and to the switch stand. With these connections made, it is an easy matter to place the switch stand so as to give the proper throw of the switch.

It is common practice to fasten the switch stand to the head-block with track spikes, but a better fastening is made with bolts. The stand is first properly placed, the holes are marked and bored, and the bolts passed through from the under side of the head-block. This obviates all danger of movement of the switch stand in fastening, which is liable to occur when spikes are used, and insures a perfect throw.

The use of track spikes is admissible when holes are bored to receive them, in which case a ½-inch auger should be used for standard track spikes. The switch stand should, when possible, be placed facing the switch, so as to be seen from the engineer's side of the engine—the right-hand side.

Next stretch a cord from the heel *a*, Fig. 27, to the point *b*, of the frog. This cord will take the position of the chord of the arc of the outer rail of the turnout curve. Mark the middle point *c* and the quarter points *d* and *e*, and at these points lay off the offsets *d d'*, *c c'*, and *e' e'*, computed as explained in *Trackwork*, Part 1. Add to these offsets the distance from the gauge line to the outside of the rail flange, and mark the points on the switch ties. Spike the rail to these marks and place the other at easy track gauge from it. Spike the rails of the turnout as far as the point of frog to exact gauge, unless the gauge has been widened owing to the sharpness of the curve. Beyond the point of frog, the curve may be allowed to vary a little in gauge to prevent a kink showing opposite the frog. In case the gauge is widened at the frog, increase the guard-rail distance an equal amount. For a gauge of 4 feet $8\frac{1}{2}$ inches, place the side of the guard-rail that comes in contact with the car wheels at 4 feet $6\frac{5}{8}$ inches from the gauge line of the frog. This gives a space of $1\frac{7}{8}$ inches between the main rail and the guard-rail. In case the gauge is widened $\frac{1}{4}$ or $\frac{1}{2}$ inch, increase the guard-rail distance an equal amount.

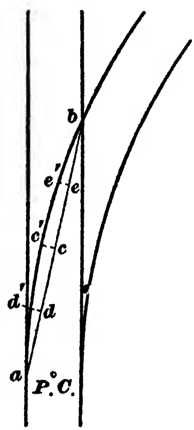


FIG. 27

When the turnout curve is very sharp, it will be necessary to curve the switch rails, to avoid an angle at the head-block. The rails should be carefully curved before being laid, and great pains should be taken to secure a perfect line.

52. To Lay Out a Point Switch.—The frog point *K*, Fig. 28, having been located exactly as for a stub switch, the lead *K B* is next laid off from *K* to the toe of switch *B*, and the positions of *B* and *D* are marked on the main-track rails. From *D*, the length *D N* of the switch rail, which is usually 15 feet, is then measured forwards to *N*, and the position of *N* is marked on the web or flange of the rail.

The heel M is usually $5\frac{3}{4}$ inches from the point N. The point I is located on a line perpendicular to MD and at a distance $\frac{1}{2}g$ from M. The point J is similarly located from the point H. As a check on the work, the length of the chord JI should have the value given in Table III.

Switch ties of the requisite number and length should be prepared and placed in the track in proper order. As in the case of stub switches, all long switch ties should be in place before the rail is cut for placing the frog; also, the ends M and L of the rails, with which the switch points connect, should be exactly even; otherwise the tie-rods will be skewed, and the switch will not work or fit well. The tie-rods should next be fastened in place, care being taken to place them in their proper order, the head-rod being numbered 1. Each rod is marked with a center punch, the number of the punch marks corresponding to the number of the rod.

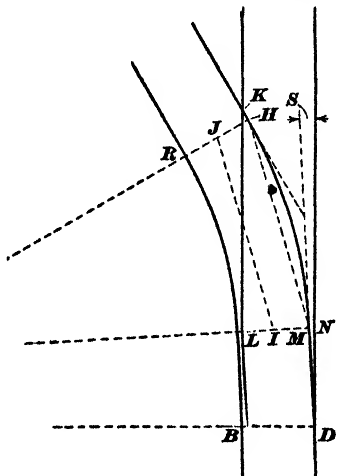


FIG. 28

The switch rails are now coupled with the rails LK and MK, and the sliding plates are then placed in position and securely spiked to the ties. The head-rod is then connected with the switch stand, and the switch is closed, giving a clear main track. The stand is then adjusted for this position of the switch, and bolted fast to the head-block. Next, rail BR is crowded against the switch point so as to insure a close fit, and secured in place with a rail brace at each tie. The laying of the rails of the turnout is then continued.

The rail MH is to be bent and spiked in place by laying off offsets from the chord MH exactly as explained for stub switches. The rail between M and H usually consists of two pieces of plain rail bent to the proper curve. The outer rail of the main track is not disturbed.

53. Laying Frogs in Track.—In placing a frog in the track, especial care should be taken to put it in perfect line and surface with the rails with which it connects. The frog should be coupled to the main-track rails, and these rails should be put in perfect line before spiking. This is more certain to give a true line to the frog than to spike the connecting rails before coupling with the frog. If the main track is in poor line, track centers are put in for lining the frog, for it is very difficult to correct defects in line after a switch is once in place. Having spiked the frog in place, the rail opposite the frog is put in perfect gauge for the full length of the frog, if on a tangent, and at the point of frog, if on a curve. To have a frog in perfect gauge, the gauge should be tried at each end of the frog, and at about 6 inches back of the frog point.

If the curve is very sharp and laid to a uniform gauge throughout, an ugly kink is left opposite the frog. This defect is caused by the frog rail, which is necessarily straight, and can be remedied by spiking the rail to gauge only at the point of frog, and allowing it to assume its natural curve for the remainder of the frog's length.

Turnout curves of long radii require long frogs, and the track can be spiked to proper gauge throughout its length without any perceptible kink at the frog.

Long frogs and long leads are the best where it is practicable to use them. The wear from sharp curves and short frogs, both on rails and rolling stock, is great, and they are to be used only where limited space requires them.

54. Switch Timbers.—Every first-class railroad has its own standards for switches, which include the necessary switch timbers. The following rule will answer well for general use:

Rule.—*To find the number of ties required for any switch lead, reduce to inches the distance from the head-block to the last long tie behind the frog, and divide this distance by the number of inches from center to center of tie; the quotient will be the number of ties required.*

EXAMPLE.—The distance from the head-block to the last tie behind the frog is 77 feet. The ties are spaced 21 inches center to center. What is the number of ties required for the switch?

SOLUTION.— 77 ft. = 924 in.; 924 ÷ 21 = 44, the number of ties required. Ans.

55. Switch ties should be 10 inches in width and at least 6 inches in thickness, though 7 inches is preferable. The head-block should be 12 inches in width, 8 inches in thickness, and 16 feet in length.

Switch ties in important yards should not be more than 9 inches apart, if they are to be kept in proper surface. It is poor economy to use inferior timber or a scant number of ties for switch ties. Switch building is expensive work, and should be made as permanent as practicable. The switch ties should be cut to proper length, marked with chalk in consecutive numbers, and a mark for the outside flange of the main-track rail should be placed on each tie.

Switch ties are cut to the proper length by the following rule:

Rule.—*Measure the length of the tie next the head-block and the length of the last long tie behind the frog. Find the difference, in inches, between them. Divide this difference by the number of ties in the switch lead; the quotient will be the increase in length per tie from the head-block toward the frog to have the ends of the ties in proper line on both sides of the track.*

56. Tamping Switch Ties.—Before tamping up a set of switch ties, the track should be raised to a uniform surface. The ties are tamped under the frog and main-track rail first, raising the frog a little higher than the rest of the switch. The head-block should also be about $\frac{1}{4}$ inch above the common surface, especially if a stub switch is used, as the continual jarring caused by wheels passing the open joint will cause the head-block to settle slightly. The middle of the ties is tamped first, and then the outer ends. This will prevent any sagging of the ties at the center and a corresponding rise at the ends. If possible, the tamping should be completed before a train passes the switch.

CROSSINGS

57. When two tracks cross each other, four frogs, called **crossing frogs**, must be introduced. The part of both tracks lying between and including these four frogs is called a **crossing**.

Fig. 29 shows a crossing for two straight tracks; the form of crossing for two curved tracks is entirely similar. This crossing is made of the best steel rails, fitted with exactness. The points are mitered, dovetailed, welded, or forged out of solid rails, the angle of the crossing and the requirements of the case determining which method is the most practicable.

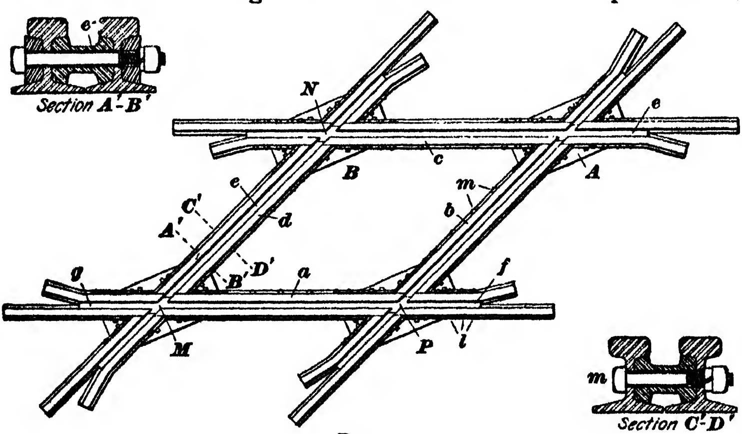


FIG. 29

The rails are mounted on strong wrought-iron bedplates A, B, etc., to which they are securely riveted through the flanges of the rails. The guard-rails a, b, c, d inside the intersecting tracks extend unbroken on all sides, and extend outside the frog points so as to guide the trucks, causing them to pass squarely through the crossing.

At all the angles, the flange way is completely filled by wrought-iron throat-fillers e, f, g, which are shaped to exactly fit the rails

Strong bolts l, m, etc., passing through the webs of the rails, the throat-fillers, and corner braces, bind the parts of the crossing firmly together.

The **dimensions** of a crossing are the angles of the four frogs, and the lengths of rail MN and MP between the gauge lines of the intersecting tracks.

58. To Find the Dimensions of a Crossing for Straight Tracks, When the Angle Between Their Center Lines is Given.—Let MN and $M'N'$, Fig. 30, be the intersecting tracks, and let F be the angle between their center lines. Then, since the sides of each frog are respectively parallel to the two center lines, each frog angle will be equal to F.

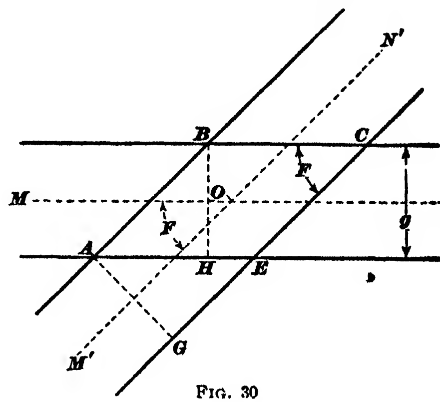


FIG. 30

From the triangle ABH,

$$AB = EC = \frac{BH}{\sin BAH} = \frac{g}{\sin F} \qquad (1)$$

Similarly, from the triangle AEG,

$$AE = BC = \frac{AG}{\sin AEG} = \frac{g}{\sin F} \qquad (2)$$

The lengths of the crossing rails are therefore all equal; that is, $AB = EC = AE = BC$.

EXAMPLE.—If two straight tracks intersect at an angle of 30°, what are the dimensions of the crossing?

SOLUTION.—Each frog angle F will be 30°. From formulas **1** and **2**,

$$AB = BC = CE = EA = \frac{g}{\sin F} = \frac{4.708}{.5} = 9.416 \text{ ft.} \quad \text{Ans.}$$

59. The crossing in the preceding example is rather long, on account of the angle of intersection of the two tracks being small. A long oblique crossing of this kind is

difficult to construct, and is very apt to cause derailment. Although there are special devices for long crossings, tracks should not be crossed at an angle of less than 45°, unless this is unavoidable, and the nearer their angle of intersection is to a right angle the better.

EXAMPLE FOR PRACTICE

Solve the example in Art. **58**, if the angle between the two center lines is 60°. Ans. $F = 60°$, $AB = BC = CE = EA = 5.44$ ft.

---

60. To Find the Dimensions of a Crossing for One Straight and One Curved Track, When the Angle of Intersection of Their Center Lines Is Given.—Let $M' N'$, Fig. 31, be the center line of the curved track, which crosses the center line of the straight track MN at A.

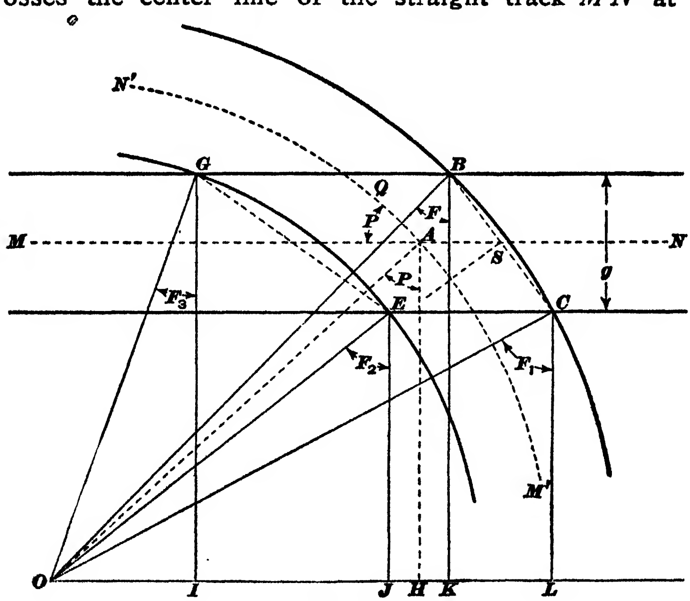


Fig. 31

Let O be the center of the curved track, and $R = OA$ be the radius; let F, F_1, F_2, and F_3 be the angles of the frogs at B, C, E, and G, respectively. Then, $F = OBK$, since OB

and BK are respectively perpendicular to the frog rails at B; and similarly, $F_1 = OCL$, $F_2 = OEJ$, and $F_3 = OGI$.

It is required to find F, F_1, F_2, and F_3 and the lengths of the chords BC, GE, EC, and GB. Let P be the angle between the center lines at A; then, $P = MAQ$, and since OA and HA are respectively perpendicular to the sides of the angle MAQ, it follows that $P = OAH$. From the triangle OBK,

$$BK = OB \cos OBK = OB \cos F \qquad (1)$$

From the triangle AOH,

$$AH = OA \cos P$$

Now, $AH = BK - \frac{1}{2}g = OB \cos F - \frac{1}{2}g$, from equation (1). Therefore, by equating the two values just obtained for AH,

$$OB \cos F - \tfrac{1}{2}g = OA \cos P;$$

or, since $OB = R + \frac{1}{2}g$, and $OA = R$,

$$(R + \tfrac{1}{2}g) \cos F - \tfrac{1}{2}g = R \cos P;$$

whence
$$\cos F = \frac{R \cos P + \frac{1}{2}g}{R + \frac{1}{2}g} \qquad (1)$$

In a similar manner, the following values are found:

From the triangle COL,

$$\cos F_1 = \frac{R \cos P - \frac{1}{2}g}{R + \frac{1}{2}g} \qquad (2)$$

From the triangle EOJ,

$$\cos F_2 = \frac{R \cos P - \frac{1}{2}g}{R - \frac{1}{2}g} \qquad (3)$$

From the triangle GOI,

$$\cos F_3 = \frac{R \cos P + \frac{1}{2}g}{R - \frac{1}{2}g} \qquad (4)$$

It may be noticed that in this case the frogs are all unequal.

61. To Find the Lengths BC, GE, EC, and GB. In the triangle BOC, draw OS perpendicular to BC. Then, $BS = OB \sin BOS$. Now, $OB = R + \frac{1}{2}g$, and $BOS = \frac{1}{2}BOC = \frac{1}{2}(BOL - COL) = \frac{1}{2}(90° - F) - \frac{1}{2}(90° - F_1) = \frac{1}{2}(F_1 - F)$. Therefore,

$$BC = 2BS = 2(R + \tfrac{1}{2}g) \sin \tfrac{1}{2}(F_1 - F) \qquad (1)$$

Similarly, from the triangle GOE,

$$GE = 2(R - \tfrac{1}{2}g) \sin \tfrac{1}{2}(F_2 - F_3) \qquad (2)$$

The following equations are obvious from the figure:

$$EC = JL = OL - OJ$$
$$= (R + \tfrac{1}{2}\, g) \sin F_1 - (R - \tfrac{1}{2}\, g) \sin F_2 \qquad (3)$$

In a similar manner,

$$GB = (R + \tfrac{1}{2}\, g) \sin F - (R - \tfrac{1}{2}\, g) \sin F_3 \qquad (4)$$

EXAMPLE.—A 6° curve crosses a straight track, the angle at the intersection of their center lines being 62°. To find the four frog angles of the crossing.

SOLUTION.—The value of R corresponding to a 6° curve is 955.37 ft.; we have also, $P = 62°$, and $\frac{1}{2}\, g = 2.35$. Substituting these values in formulas **1** to **4**, Art. **60**,

$$\cos F = \frac{955.37 \cos 62° + 2.35}{955.37 + 2.35}; \text{ whence } F = 61°\ 54'\ 55''. \quad \text{Ans.}$$

$$\cos F_1 = \frac{955.37 \cos 62° - 2.35}{955.37 + 2.35}; \text{ whence } F_1 = 62°\ 14'\ 0''. \quad \text{Ans.}$$

$$\cos F_2 = \frac{955.37 \cos 62° - 2.35}{955.37 - 2.35}; \text{ whence } F_2 = 62°\ 5'\ 3''. \quad \text{Ans.}$$

$$\cos F_3 = \frac{955.37 \cos 62° + 2.35}{955.37 - 2.35}; \text{ whence } F_3 = 61°\ 45'\ 50''. \quad \text{Ans.}$$

EXAMPLE FOR PRACTICE

A 7° curve crosses a straight track so that the angle of intersection of their center lines is 60°. Find the four frog angles, expressing each angle to the nearest 10″, or $\frac{1}{6}$ minute.

$$\text{Ans.}\begin{cases} F = 59°\ 54'\ 20'' \\ F_1 = 60°\ 17'\ 0'' \\ F_2 = 60°\ 5'\ 40'' \\ F_3 = 59°\ 42'\ 50'' \end{cases}$$

---

62. To Find the Dimensions of a Crossing for Two Curved Tracks That Curve in the Same Direction. Let O and O_1, Fig. 32, be the centers of the two curves, and let $R = OA$ and $R_1 = O_1A$ be their respective radii. Since OA and O_1A are perpendicular to the respective center lines at A, the angle $OAO_1 = P$ is the angle between the center lines of the two curves.

The method of computing the four frog angles is as follows: In the triangle OAO_1, the sides $OA = R$, $O_1A = R_1$ and the angle P are known; hence, the side $k = OO_1$ can be computed by trigonometry. Then, in each of the triangles OBO_1, OCO_1, OEO_1, and OGO_1, the three sides are

known, and the angles F, F_1, F_2, and F_3 can be computed from equation (1), Art. **44.**

The chords GB, EC, BC, and GE are next computed as follows: In the triangle BO_1O, in which $OB = R + \frac{1}{2}g$,

$$\sin BO_1O = \frac{R + \frac{1}{2}g}{k} \sin F \qquad (1)$$

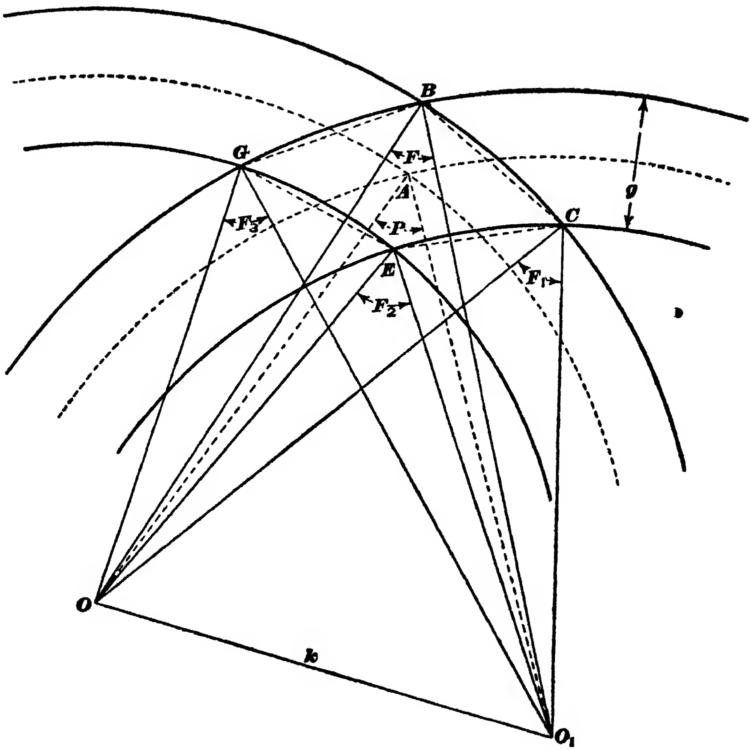


Fig. 32

and in the triangle GO_1O, in which $OG = R - \frac{1}{2}g$,

$$\sin GO_1O = \frac{R - \frac{1}{2}g}{k} \sin F_3 \qquad (2)$$

In the triangle BO_1G,

$$BO_1G = BO_1O - GO_1O \qquad (3)$$

Also,

$$BG = 2\,(R_1 + \tfrac{1}{2}g) \sin \tfrac{1}{2} BO_1G \qquad (4)$$

In a similar manner, the angles $E O_1 C$, $B O C$, and $G O E$ are computed; the chords are then found by the formulas

$$E C = 2\left(R_1 - \tfrac{1}{2} g\right) \sin \tfrac{1}{2} E O_1 C \qquad (5)$$

$$B C = 2\left(R + \tfrac{1}{2} g\right) \sin \tfrac{1}{2} B O C \qquad (6)$$

$$G E = 2\left(R - \tfrac{1}{2} g\right) \sin \tfrac{1}{2} G O E \qquad (7)$$

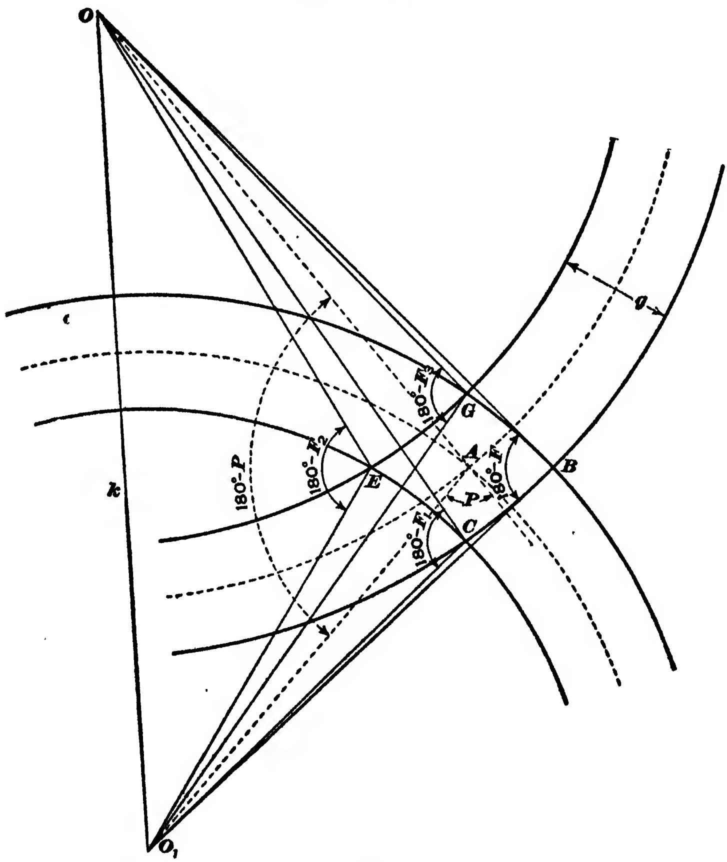


Fig. 33

The complete computation of the dimensions of the crossing is thus seen to be a very long one. Fortunately, it needs to be performed but very seldom, since two tracks will not be crossed on a curve when this can be avoided.

As a test of the entire work, it should be found that the frog angles do not differ very greatly, the total range probably being less than 1°, and that the mean of the four angles will not differ by more than a few seconds from the angle P of intersection.

63. To Solve the Problem of the Preceding Article When the Two Tracks Curve in Opposite Directions. This location is shown in Fig. 33, the lettering and notation of which are exactly the same as those of Fig. 32. If the triangles of the two figures are compared, it will be seen that the expressions for the sides of these triangles are exactly the same in both; thus, in either figure, $O\,O_1 = k\,O_1\,C = R_1 - \frac{1}{2}g$, etc. The angles of the triangles at A, B, C, E, and G, Fig. 32, are equal, respectively, to P, F, F_1, F_2, and F_3, but in Fig. 33 they are equal, respectively, to the supplements of these angles; that is, in Fig. 33, $O\,A\,O_1 = 180° - P$, $O\,B\,O_1 = 180° - F$, etc. The solution is the same in principle as that of the problem in the preceding article.

RAILROAD BUILDINGS AND MISCELLANEOUS STRUCTURES

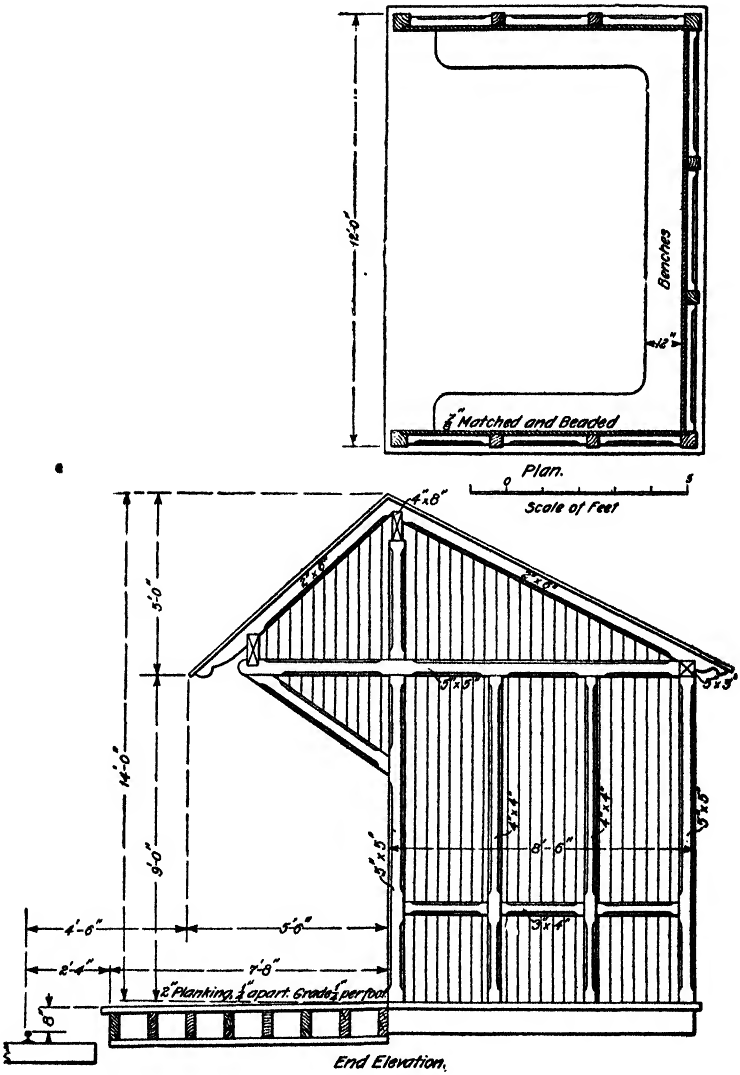
BUILDINGS

STATIONS

1. Platforms.—The simplest kind of station is a mere platform. In its cheapest form, this is made of wood. Sometimes, platforms are made level with the top of the rail, and if so, may be built up to the outer rail head. Higher platforms are more convenient, as they lessen the step-up to the first car step, but they should not be closer to the track center than 4 feet 8 inches, or, say, 2 feet 2 inches from the outer head of the rail. Sometimes, the platforms are made of cinders, or of fine crushed stone, confined by curbs of stone or wood. These platforms are cheap, but in muddy weather dirt will be tracked into the car. Bricks set on edge on a foundation of sand are very good, durable, and inexpensive. For large first-class stations, a concrete platform with a top coat of sand and cement is by far the best form.

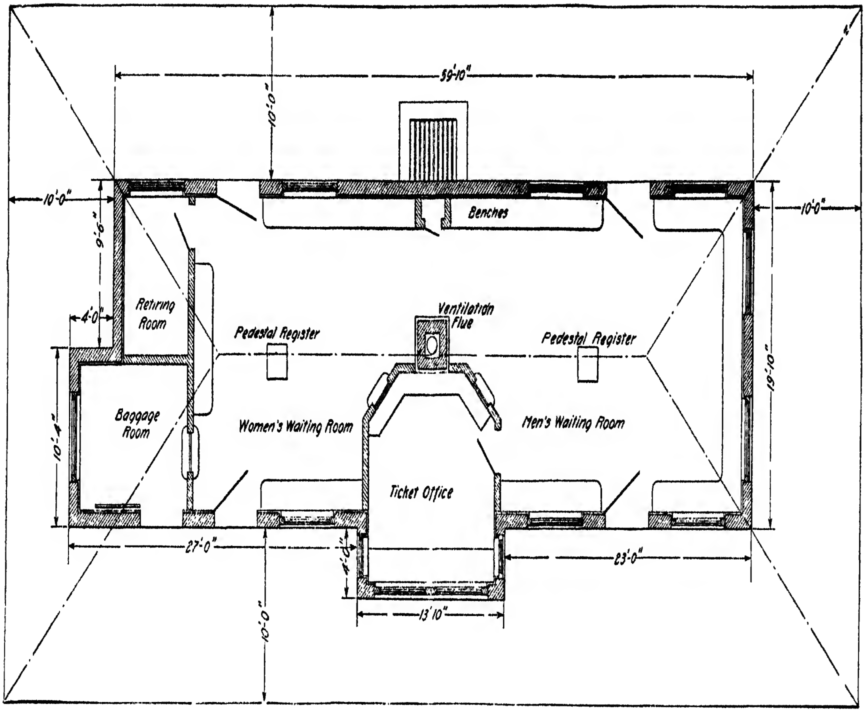
2. Shelter Sheds.—A shelter shed is usually considered essential for even the most unimportant flag station. A design that combines economy with efficiency is shown in Fig. 1.

3. Passenger Stations.—A complete treatment of passenger stations is beyond the scope of this Course. Some

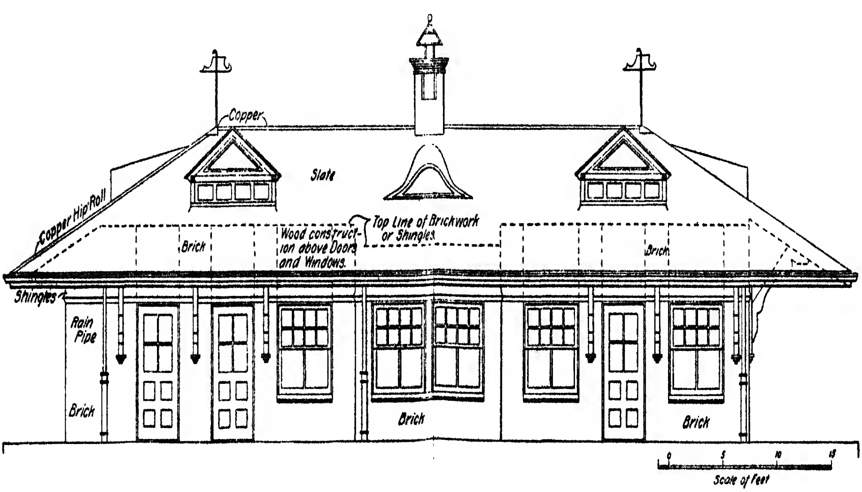


12'-0"
Benches
12"
7/8" Matched and Beaded
Plan.
0
5
Scale of Feet
4"x8"
2"x6"
2"x6"
5'-0"
5"x5"
5"x5"
14'-0"
4"x4"
4"x4"
5"x5"
5"x5"
8'-6"
9'-0"
3"x4"
4'-6"
5'-6"
2'-4"
7'-8"
2" Planking 1/4" apart. Grade 1/4" per foot
8"
End Elevation.

FIG. 1



59'-10"
10'-0"
10'-0"
10'-0"
9'-6"
4'-0"
10'-4"
19'-10"
27'-0"
23'-0"
4'-0"
13'-10"
10'-0"
Benches
Retiring Room
Ventilation Flue
Pedestal Register
Pedestal Register
Baggage Room
Women's Waiting Room
Men's Waiting Room
Ticket Office



Copper
Slate
Copper Hip Roll
Top Line of Brickwork or Shingles
Wood construction above Doors and Windows.
Brick
Brick
Shingles
Rain Pipe
Brick
Brick
Brick
0
5
10
15
Scale of Feet

FIG. 2

of the fundamental principles, however, will be here indicated. A plan of a small station is shown in Fig. 2.

An office for the agent and a waiting room will represent the absolute minimum for a passenger station. As the demand for quarters increases, there will be added successively a baggage room, toilet rooms, and an express office The more modern plan is to have one large waiting room for both men and women. Some of the very smallest freight stations combine the passenger and freight business under one roof; but it is usually desirable to have the freight storage warehouse separate from the passenger station, even though one agent does the work of both departments. The duties of the agent at small stations usually include that of telegraph operator, to transmit train orders to the trainmen. The design of the station is very likely to include a bow window, which permits the agent or telegraph operator to look up and down the line in either direction to observe approaching trains. Sometimes, even though the road makes no pretense to systems of block signaling, the telegraph operator can signal to an engineman by means of a signal board or flag suspended immediately outside the station and operated from inside the station office.

SECTION BUILDINGS AND ENGINE HOUSES

4. Section Tool Houses.—At the headquarters of each section, a tool house is erected for the storage of hand and push cars, track tools, and all track materials that may be damaged by exposure to the weather, or, on account of their portability, are likely to be stolen. Among the latter class are track bolts and track spikes, nails and cut spikes, shim and pin timber, etc. The tool house should be placed convenient to the house occupied by the section foreman, so that all tools and material may be near his hand either for repair or inspection, or for use in case of an emergency. All tools and material contained in the tool house should be kept in perfect order and repair. The house should rest on a substantial foundation of masonry, and stand fully 12 inches

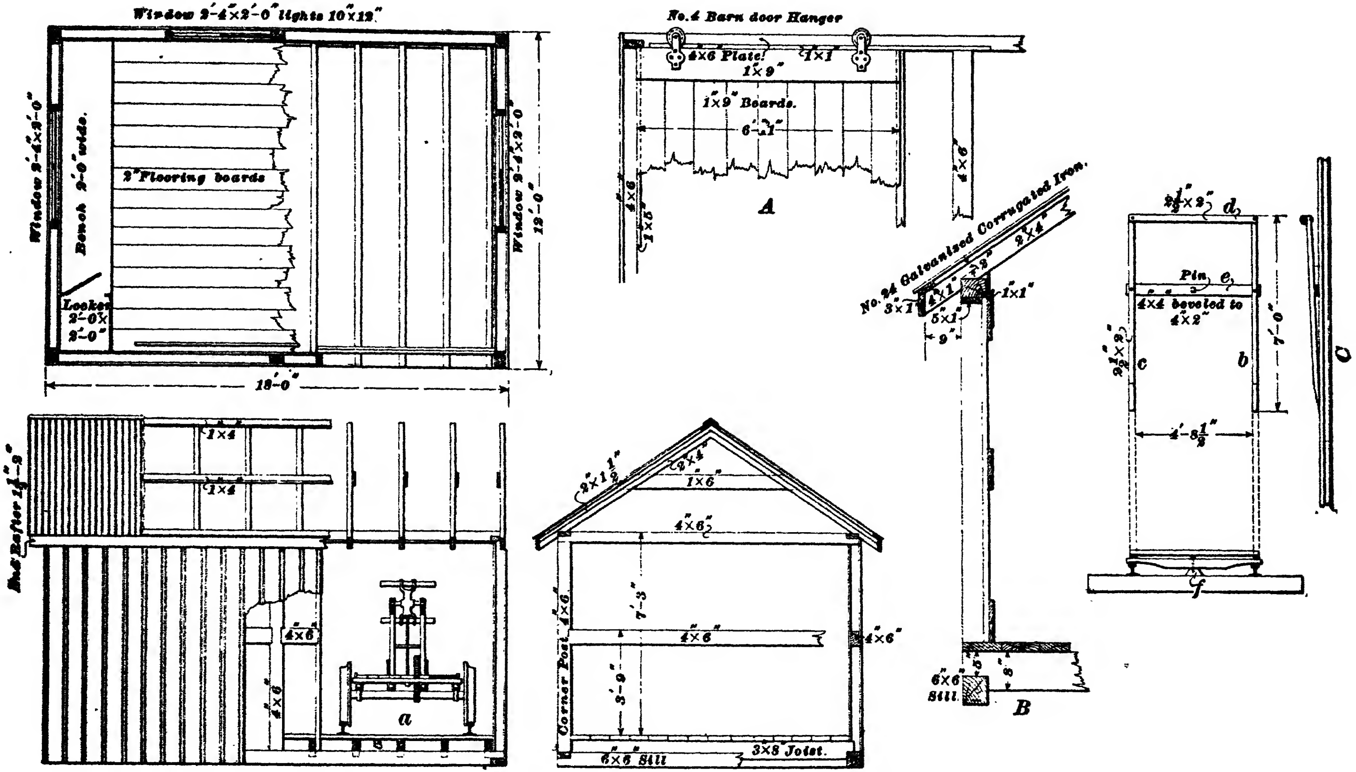

Window 2'-4"×2'-0" lights 10"×12"
Window 2'-4"×2'-0"
Bench 2'-0" wide.
2" Flooring boards
Locker 2'-0"× 2'-0"
Window 2'-4"×2'-0"
12'-0"
18'-0"
No. 4 Barn door Hanger
4×6" Plate
1×1"
1"×9"
1"×9" Boards.
6'-1"
4"×6"
1"×5"
A
No. 24 Galvanized Corrugated Iron.
2"×4"
3"×1"
4"×1"
1"×1"
5"×1"
9"
6"×6" Sill.
B
2½"×2"
d
Pin
e
4×4 beveled to 4"×2"
7'-0"
c
b
4'-8½"
f
C
1×4
1×4
End Rafter 1½"-2"
4"×6"
4"×6"
a
2"×1½"
2"×4"
1×6"
4"×6"
7'-3"
3'-9"
Corner Post 4"×6"
6"×6" Sill
3"×8" Joist.

FIG. 3

above the surface of the ground, so as to allow ample circulation of air among the floor timbers. A building fully meeting the requirements of a tool house is shown in Fig. 3. At one end of the house is a work bench fitted with a vise, together with wrenches, hammers, hand saws, punches, and any other tools necessary in making repairs of tools or track. The hand and push cars rest on a permanent track, shown at *a*. They are admitted through a sliding door shown in detail at *A*. A device for transferring the hand car to the tool-house track is shown at *C*: it consists of two oak pieces *b* and *c*, which serve as rails and are held at gauge by the cross-piece *d* and the bolster *e*, which are bolted to the strips. A pin passes through the bolster *e* into a socket in the cast-iron portable pedestal *f* on which the frame revolves. In operation, the pedestal is placed on a tie with the pieces *c*, *b* lying directly on the rails. The hand car is then run on the frame, which is revolved so as to connect with the tool-house track.

The tool house should be well provided with racks, on which the various tools of the section may be safely and economically stored. Hooks of iron or of wood nailed to the sides of the house are especially handy for hanging up shovels. A locker built under the work bench is useful for storing lanterns and oil cans. A section through the door is shown in detail at *B*. The roof covering is of corrugated iron, which also serves as a protection against fire.

The plan shown in Fig. 3 may be used as a guide for building a safe and economical tool house.

5. Section Dwelling Houses.—Dwelling houses for section men should be substantial, neat, and of moderate size and cost. A house meeting these requirements is shown in Figs. 4 and 5. The cost of such houses is fully justified by the advantages of having section men on hand at any time of day or night—especially for emergencies. There is even a direct return in the corresponding reduction in wages on account of free house rent. The house shown in Figs. 4 and 5 has a balloon frame, is strong, and may be built by any carpenter of average intelligence. It

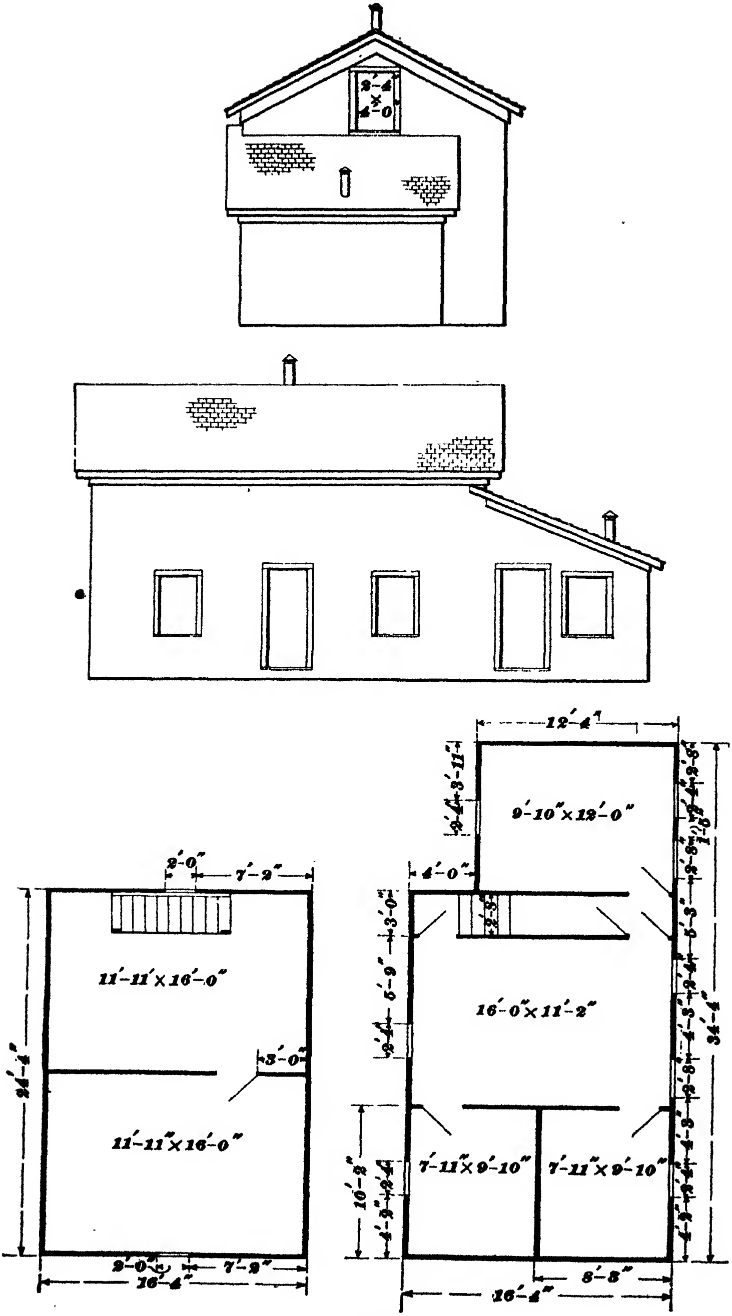

2'-4" × 4'-0"
2'-0"
7'-2"
11'-11' × 16'-0"
3'-0"
11'-11" × 16'-0"
24'-4"
2'-0"
7'-2"
16'-4"
12'-4"
9'-10" × 12'-0"
4'-0"
16'-0" × 11'-2"
7'-11" × 9'-10"
7'-11" × 9'-10"
10'-8"
34'-4"
8'-8"
16'-4"

FIG. 4

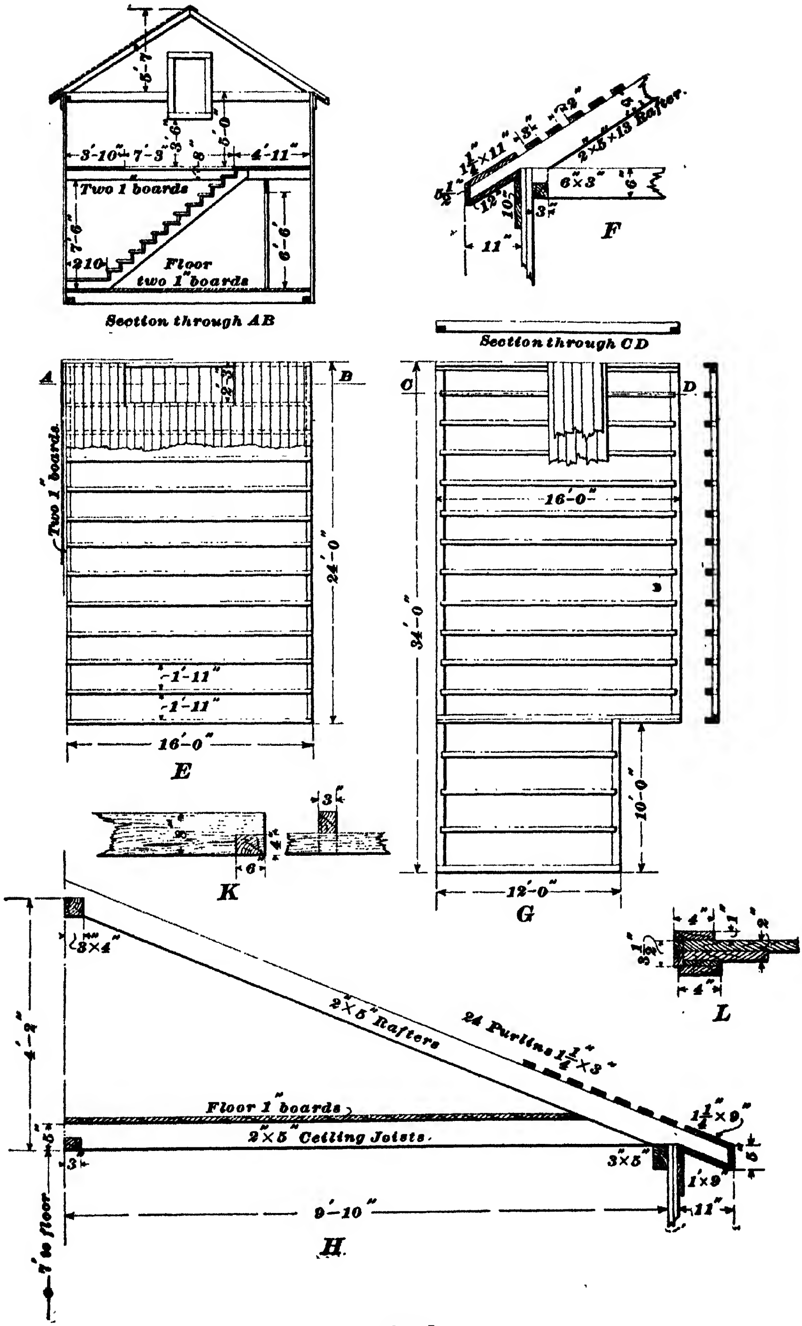

Section through AB
Two 1" boards
Floor two 1" boards
Section through CD
A
B
C
D
16'-0"
24'-0"
34'-0"
10'-0"
12'-0"
1'-11"
E
F
G
K
L
H
2"×5" Rafters
24 Purlins 1¼"×3"
Floor 1" boards
2"×5" Ceiling Joists
3×4"
3"×5"
1'×9"
1¼"×9"
9'-10"
4'-2"
11"
7' to floor

FIG. 5

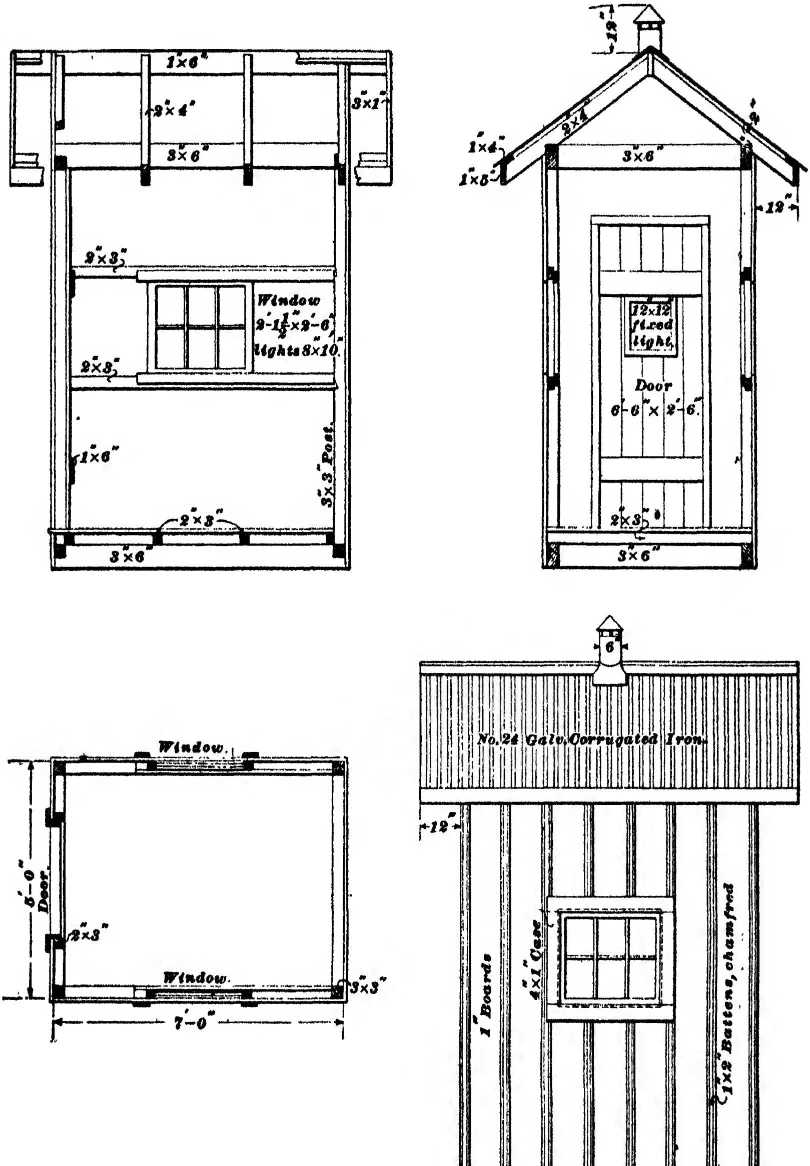
provides ample accommodation for a family of eight, and will contain twelve with but little crowding. The outer walls and partitions consist of two courses of 1-inch boards nailed vertically to the frame. The boards should be surfaced on one side, ship-lapped, and well seasoned before being put in place, thus giving a smooth surface on both sides of the walls, and one that will take paint well.

Door and window casings should be of pine. The ground floor may be of material similar to that used for the walls, except that the floor boards should be tongued and grooved. Complete framing plans are shown in Fig. 5, which may serve as a guide to those undertaking similar work. The cross-section *A B* shows the arrangement of the stairs and the spacing of the floors. A framing plan of the second floor is shown at *E*, and of the first or ground floor at *G*. A detail of the roof frame of the main body of the house is shown at *F*, and of the roof of the addition at *H*. A detail of the sill and floor joist is shown at *K*, and of a door casing at *L*. The roof covering, like that of the tool house, should be of corrugated iron.

6. Watchman's Shanty.—A watchman's shanty should be large enough to accommodate comfortably one man—no more. This will include space for a stove for warming the building in winter. A general plan for such a shanty is given in Fig. 6.

7. Engine Houses.—For an engine house with a capacity of only four engines, the rectangular form is best. The house should have two parallel tracks; it should be so designed that it can be entered from either end, and should have a length of about 150 feet, or somewhat in excess of two of the longest engines on the road. Unless the engine house can be entered from either end, a dismantled engine on one track may block another engine on the same track. If many stalls are required, a roundhouse is preferable, and is the more economical form.

A **roundhouse** is usually a building constructed between two arcs of circles, the inner arc having a radius of at least



1"×6"
2"×4"
3"×1"
3"×6"
2"×3"
Window 2'-1½"×2'-6", lights 8"×10".
1"×6"
3"×3" Post.
2"×3"
3"×6"
12"
2×4
1×4
1×5
3×6
12"
12×12 fixed light.
Door 6'-6"×2'-6".
2"×3"
3"×6"
Window.
5'-0"
Door.
2"×3"
Window.
3"×3"
7'-0"
6
No. 24 Galv. Corrugated Iron.
12"
1" Boards
4"×1" Case
1"×2" Battens, chamfred

FIG. 6

50 feet, and the outer a radius about 80 feet greater. The arcs are sometimes whole circles, but usually they are not larger than a half circle. A turntable is placed with its center at the center of the circles. This turntable serves not only the usual purpose of a turntable, but also affords easy access to any stall. A roundhouse permits the accommodation of a larger number of engines within a limited space than a rectangular engine house. The wall toward the turntable is composed entirely of the doors and the posts between them on which the doors hang and which support the roof. The outer wall is preferably made of brick or concrete, although wood is sometimes used for the sake of economy.

The construction of the roof is a serious problem, which taxes the ingenuity of engineers. Engines run into the engine house under their own steam, and, even if the fires are immediately drawn, there is a considerable discharge of the gases of combustion. Besides, engines must be fired up before starting out. The gases of combustion rapidly corrode any steel that may be placed in the framing of the roof. It is, therefore, almost useless to employ steel roof trusses, which would otherwise be an ideal form of roof framing. Wood is the material used most commonly for this purpose. Of late years, however, reinforced-concrete roofs have been successfully constructed. Part of the trouble is avoided by the use of **smoke jacks**, which drop down over the stack of an engine when the latter has reached its designed place. The material of the smoke jacks is difficult to select: galvanized iron would be a good material were it not for its rapid corrosion; vitrified pipe has been tried, but it breaks too easily; cast iron has been used, but it is expensive and very heavy. Sometimes, smoke jacks are made of wood, which is painted with a so-called fireproof paint. This paint prevents the wood from catching fire under ordinary circumstances.

MISCELLANEOUS STRUCTURES AND ACCESSORIES

WATER STATIONS

8. Water stations are points along a railroad where the engines stop to take in water. The distance between these stations depends mainly on the amount of traffic and somewhat on the grades. On roads with a light traffic, water stations at intervals of 15 miles will meet every requirement, while roads with a heavy traffic and frequent trains may require them at every 5 or 6 miles.

Water stations usually consist of large wooden tubs placed on strong frameworks and supported by heavy pillars resting on foundations of masonry. The tubs are generally circular in form, the bottom diameter being a few inches larger than the top diameter, in order that the iron hoops may be driven tight. White pine, cedar, and redwood are the varieties of timber chiefly used in the manufacture of tanks. The staves are planed by machinery specially designed to give them the proper bevel, so that when set up the joints are close and water-tight. The staves are fastened together at the top with a single dowel between each two, merely to hold them in place while being set up. The bottom of the tank is formed of pieces doweled together and fitted into a groove about 1 inch in depth, which is cut in the staves to receive them. The hoops are fastened together with lugs that grip the two ends of the hoop. The two lugs are united by a bolt threaded at both ends and fitted with nuts, by the screwing up of which the hoops are tightened. The hoops are first nearly driven to place, the lugs are then tightened with a wrench, and the driving is then finished.

9. Railroad water tanks hold from 20,000 to 40,000 gallons. A common size is 16 feet in diameter by 16 feet high,

and holding about 21,000 gallons. All tanks built to contain more than 10,000 gallons are made from 3-inch stuff. This thickness is somewhat reduced by planing. The bottom of the tank should be from 10 to 12 feet above the tops of the rails. It is a common practice to enclose the tank in a framed structure, the foundation and post supports forming the first story, and the tank, together with its covering, the second story. Where the supply of water is pumped, the first story is often used as a pump house, and a fire is usually maintained in winter to prevent freezing of the water. At divison or terminal points, where many engines are to be supplied, the tank is made proportionately larger, and often two tanks are placed together.

10. It is desirable to combine a coaling with a water station, in order that an engine may take both fuel and water at the same time. Such an arrangement is usually made at division points and terminals, though it is not always practicable to place a water tank and a coaling station side by side. A tender of coal will serve for several tank loads of water, so that coaling stations situated at division points, at intervals of, say, 100 miles, will serve every requirement.

11. A water tank has three pipes: an inlet pipe by which the water enters the tank; a waste pipe for preventing overflow; and a discharge pipe, or feedpipe, 7 or 8 inches in diameter, in or near the bottom, through which the water flows to the tender tank. The discharge pipe is from 8 to 10 feet long, and is jointed at the end that joins the tank, so that, when the tender tank is filled, the discharge pipe, acted on by a counterweight, swings either sidewise or vertically on its hinge joint, out of reach of the cars. The discharge pipe at its connection with the tank is provided with a valve having a lifting gate. Movement is communicated to this gate by means of a lever, the short arm of which is attached to the valve rod. The long arm of the lever has a rope attached, which hangs within reach of the engineman.

When taking water, the discharge pipe is lowered and swung over the water hole in the tender tank. The engineman then

pulls down on the lever. This action raises the valve stem and allows the water to flow from the water tank into the tender tank. Tender tanks hold from 2,500 to 3,500 gallons. Some of the more recent engines have tanks with capacities of 5,000 and 6,000 gallons.

12. Source of Water Supply.—The least expensive and most satisfactory water supply is that obtained from either springs or brooks that have sufficient elevation to deliver water into the tank by gravity and so avoid the expense of pumping. Care must be taken, however, not to use water that is too hard. Clear, pure water, as free as possible from mineral matter in solution, is greatly to be desired. If the stream from which the supply is obtained is likely to become muddy from freshets, a reservoir of suitable size should be constructed and kept constantly full of clear water, so that, in case of a freshet, the flow of the water into the reservoir may be stopped until the stream runs clear.

Where spring water is used, and the supply in times of drought is likely to run short, a reservoir of ample capacity should be constructed and the surplus water stored for future use.

When the source of supply is too low for the water to be delivered by force of gravity, resort is had to pumping. Steam and gasoline engines and wind power are employed to operate the pumps. Pumping by means of windmills is the least expensive, and, but for occasional calms, the most satisfactory. The only way to provide against a short supply due to calms is to make the capacity of the water tanks such that they will hold a supply sufficient for a number of days.

13. Standard Water Tanks.—A general plan of a standard water tank is given in Fig. 7. The foundation is shown in plan at *A*; a plan of the arrangement of the timbers composing the tank seat or deck is shown at *B*; and a complete elevation of the tank at *C*. The foundation, which should be made, in the most substantial manner, of well-dressed stone laid in cement mortar, consists either of

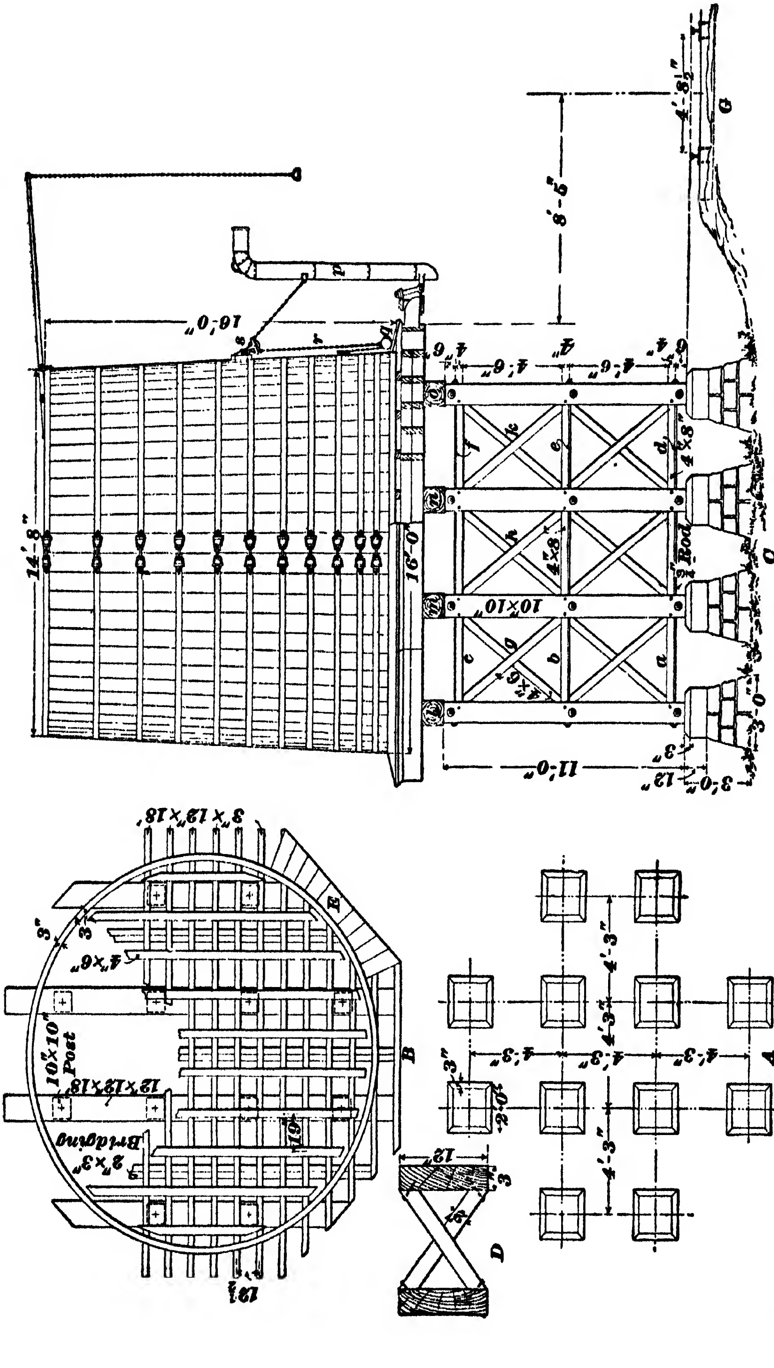

14'-8"
16'-0"
16'-0"
8'-5"
4'-8½"
11'-0"
10"×10"
4"×8"
4"×6"
¾" Rod
3"×12"×18"
12"×12"×18"
10"×10" Post
2"×3" Bridging
4"×6"
4'-3"
2'-0"
A
B
C
D
E
G

FIG. 7

continuous walls laid at right angles, on which the sills are placed and the posts mortised into them, or of a pediment of pyramidal form built for each post, as shown in the figure. Each post is secured to its pediment by a dowel 1 inch in diameter and 6 inches in length. The stone pediment forms a very substantial foundation; it is effective in appearance and does away with the sills, which are likely to decay from alternate wetting and drying.

The posts are connected together by girts *a*, *b*, *c*, which are tenoned into the posts and fastened with treenails. This connection is further strengthened by $\frac{3}{4}$-inch tie-rods *d*, *e*, *f*, which pass through each row of posts, a cast washer being placed under the head and nut of each tie-rod. Between each two rows of girts, a series of **X** braces *g*, *h*, *k* is placed and securely spiked to the posts and girts. The caps *l*, *m*, *n*, *o*, on which the beams that compose the deck rest, are 12 in. × 12 in., and are fastened to the posts by a mortise and tenon. The deck is composed of two sets of timbers laid at right angles to each other. The first set, laid directly on the caps, are 3 in. × 12 in., and uniformly spaced. The timbers are held together and strengthened by bridging (see detail *D*) besides being spiked to the caps. The second set, which are 4 in. × 6 in., and laid at right angles to the floorbeams, are spaced 19 inches center to center, and extend to within 3 inches of the tank staves. The deck timbers are in direct contact with the bottom of the tank, and receive the entire weight of the water contained therein without allowing any of its weight to rest on the staves. The deck is usually made octagonal in form, and, in case the tank is not covered with a house, is projected far enough from the tank (as shown at *E*) to protect the foundation and timber supports from the weather. The sides of the tank flare or batter outwards at the rate of $\frac{1}{2}$ inch to the foot, so that the hoops will drive tight.

The discharge pipe *p*, when not in use, takes the position shown in the figure, being held in that position by the weighted ball *q*, which is attached to the chain *r*, running through the sheave *s*, and thence to its connection with the discharge pipe. A cross-section of the track is shown at *G*,

the top of the rail being 12 feet below the outlet of the discharge pipe.

14. The valve connection of the discharge pipe with the tank is shown in Fig. 8. The connection may be made through either the side or the bottom of the tank. The bottom valve connection is shown in the figure. The valve rod *a* is attached to the short arm of the lever *b*. The weight *c*, attached to the end of the short arm of the lever, holds the valve firmly in place. A rope is attached to the end *d* of the long arm of the lever and hangs within reach of

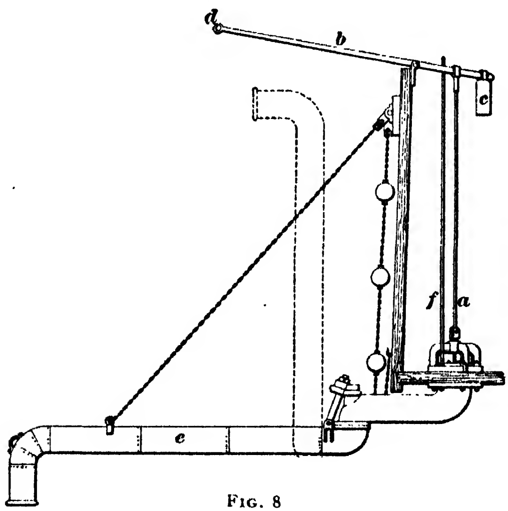


FIG. 8

the engineman. By pulling down on this rope, the valve is raised and the water flows through the discharge pipe *e* to the tender tank. The vacuum pipe *f* admits air to the discharge pipe after the valve comes to its seat, so that the discharge pipe is quickly emptied.

15. Water Columns.—Where space is limited and the head of water is sufficient, a **water column** (see Fig. 9) is used in place of a tank. It occupies very little space, and can safely be placed between the parallel tracks of a double-track road, so it will serve engines on both tracks equally well.

A water column consists of a globe valve *a*, connecting with the main water pipe *b*, and enclosed in a chamber of brick masonry. This chamber is covered with a substantial floor of timber, and forms the foundation for the pedestal *c*, which supports the crane-shaped water column *d*. This column is jointed at its connection with the pedestal, so that the discharge pipe may be readily swung over the tender when taking water. The cast-iron globe *f*, Fig. 10, is connected with the valve disk by means of the valve rod *g*, and by its weight keeps the valve closed. When taking water, the lever *h* is depressed. This causes the short arm *k* of the lever to rise, and lifts the globe *f*. The weight being thus removed from the valve, the disk is lifted by the pressure

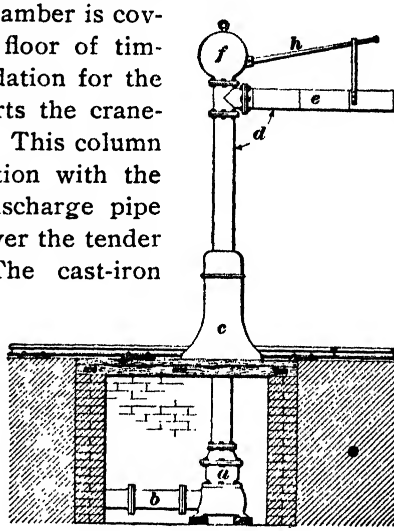


FIG. 9

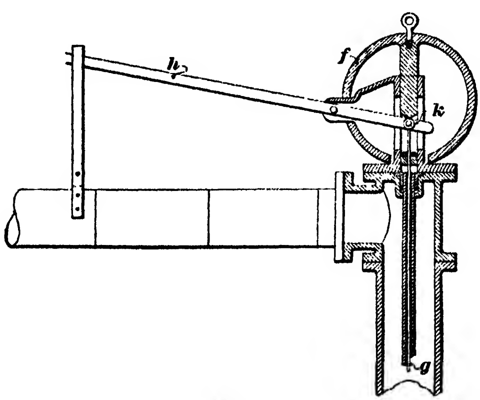


FIG. 10

of the water that flows through the discharge pipe to the tender tank.

16. Track Tanks.—The demand for high-speed express trains requires that trains shall make continuous runs of from 50 to 100 miles. Unless the tender tank has unusual capacity, it will not hold sufficient water for such a run. To obviate the necessity of making stops for a supply of water, the device of **track tanks** is employed. The length of a track tank is necessarily $\frac{1}{4}$ mile or more. The tank must be located on a stretch of *perfectly level* track. As it is not usual to find at a convenient location a stretch of perfectly level track with a length of $\frac{1}{4}$ mile, the construction of such a tank usually implies a regrading of the track for a total length of perhaps 1 mile, in order that the level stretch may be obtained, and in order that the approaches to this level stretch may not require too steep a grade. The tank or trough is made of $\frac{3}{16}$-inch steel plate, and is 19 inches wide, about 6 inches deep, and about 1,300 feet long. The steel plates are stiffened with lines of angle bars. Ordinary track spikes are driven with their heads over the flanges of the angle irons, which permit the two ends of the tank to expand or contract freely, from changes in temperature, by sliding under the spike heads, just as does a railroad rail.

A scoop must be attached to the tender of each engine that uses the tank. The scoop connects directly with a curved pipe that runs backwards and upwards through the tender, and by curving around discharges the water directly into the top of the tank. The mere velocity of the train causes the water to rush into the scoop, up the pipe, and into the tank. The scoop is raised or lowered by a chain. An inclined plane is provided that throws up the scoop, in case the fireman neglects to raise it before it reaches the farther end of the tank. The scoop is then automatically locked where it will be out of the way of any low obstruction that it might otherwise strike.

To prevent freezing in winter, track tanks must be provided with pipes connecting directly with a steam boiler. The pipes are perforated at frequent intervals with holes about $\frac{1}{8}$ inch in diameter. Live steam from the boiler is forced through these pipes and into the water of the tank.

This keeps the water sufficiently heated to prevent freezing. The amount of steam required for such heating is even greater than that required for pumping.

Although track tanks are chiefly useful in providing for fast passenger trains, roads that have such tanks equip nearly all their locomotive tenders with scoops, so that water may be obtained from the tanks when necessary, since the added expense of equipping the locomotives is comparatively small when the plant is once established. The plant is usually provided with a standard water tank, as has been previously described, from which the supply for the track tank can be obtained. There should also be a water column for the use of any engine not provided with scoops.

The cost of installing a track tank depends on the amount of regrading necessary, and on whether the tanks are provided for two, three, or four tracks. Ordinarily, no road with less than two tracks would feel justified in installing such a plant. The cost of installation for a double-track road may be approximately stated as $10,000 to $12,000, while the expense of maintenance will run from $125 to $150 per month.

COALING STATIONS

17. Coaling stations are points along a railroad where fuel is kept in stock for supplying locomotives. The stations are placed at all division points, large yards, and sometimes at the summits of long grades where pushers are employed. Formerly, many roads used wood as fuel, but coal, which is far more lasting and more economical of space, is now almost universally used. The coaling stations of 30 years ago were very primitive in design. The fuel was loaded by hand, the coal being shoveled into small carts and dumped from a platform into the tender. A very decided advance in design was made when coal pockets (see Fig. 11) were introduced. The pockets are supported on bents of trestlework, each pocket comprising the space between two bents. The figure shows the cross-section at *A*, and the side elevation at *B*. Each bent is supported by four posts *a*, *b*, *c*, and *d*. All are vertical

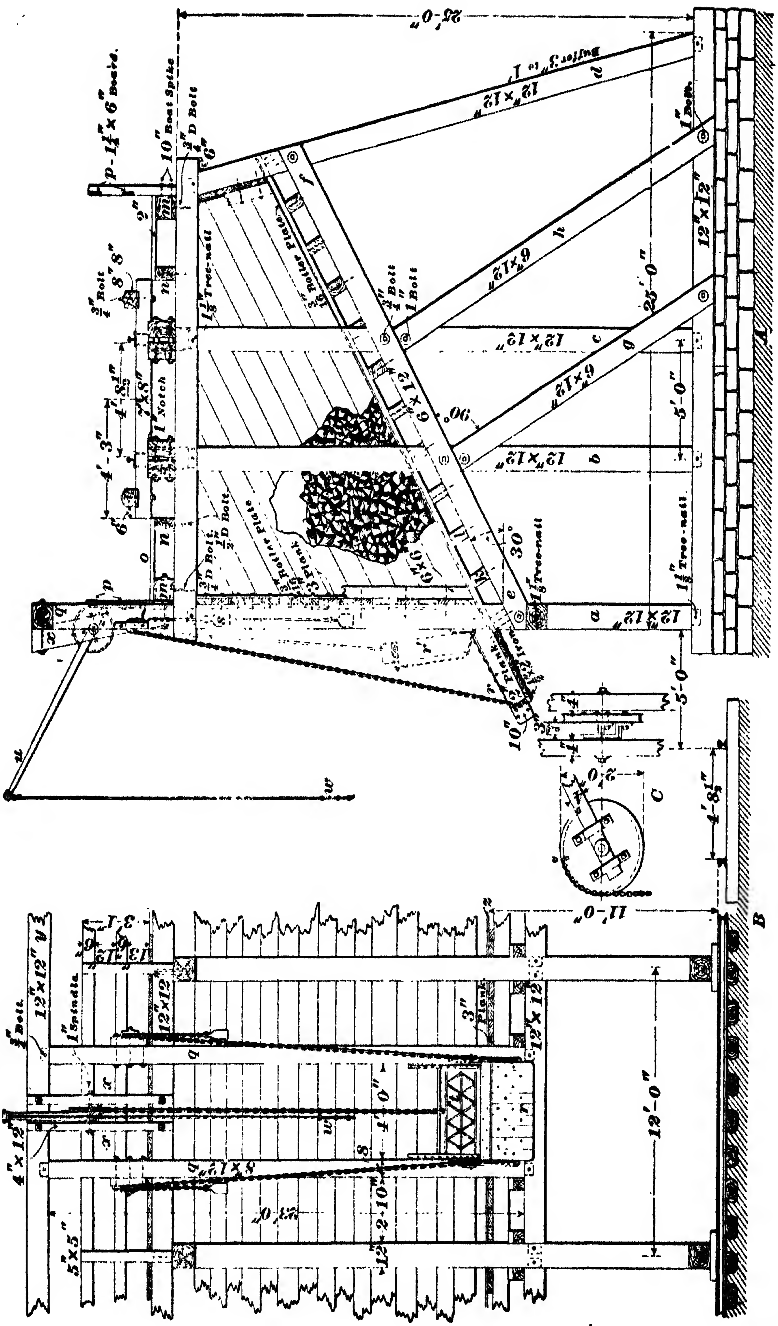


FIG. 11

except the last, *d*, which has a batter of 3 inches to the foot. Timbers *e f*, 6 in. × 12 in., are bolted to both sides of the posts and supported by batter posts *g*, *h*, also 6 in. × 12 in., which are bolted to both post and sill. These combined form the support to the pocket floor system, which consists of 6 in. × 10 in. floorbeams *k*, *l*, etc., laid 2 feet center to center, as shown in the figure, and drift-bolted to the supports. On these floorbeams is laid a flooring of 3-inch oak planks, which are covered with plates of sheet iron from $\frac{1}{8}$ to $\frac{3}{16}$ inch in thickness to protect them from the wear of the coal.

The bents are spaced 12 feet center to center, and planked on both sides above the floor with 3-inch timber, forming a series of pockets. This plan provides for storing coal of different sizes, so as to meet the requirements of the different types of engines. The partition walls are also protected with sheet iron. The track stringers are placed directly over the middle posts. They consist of two pieces 8 in. × 16 in., and extend over two bents, as in ordinary trestle building. The ties are 7 in. × 8 in. × 10 ft., and are notched down 1 inch on the stringers. They carry an 8 in. × 8 in. guard-rail, which is also notched 1 inch on the ties. Stringers are fastened to the cap with drift bolts made of $\frac{3}{4}$ in. × 24 in. round iron. Stringers are spaced 3 inches, and held in place by separators of cast iron. Stringer bolts are $\frac{3}{4}$ in. × 22 in. in size. The bents are further tied together by the timbers *m*, *m*, 12 in. × 12 in., which are fastened to the caps with $\frac{3}{4}$ in. × 20 in. drift bolts, and by the timbers *n*, *n*, 6 in. × 12 in., which partly support the plank walks *o*. These walks are protected by a railing *p p*, which is supported by posts spiked to the timbers *m*, *m*.

The coal is conducted from the pocket to the tender by means of a spout or chute made of planks and sheet iron. This chute, when in position for coaling a tender, is represented by *r*, and when not in use, by *r′*. It is fitted with counterweights *s*, somewhat heavier than itself, which enable the engineman to handle it with ease. The mouth of the pocket is closed by a sliding cast-iron door *t*, which works

in guides, and is operated by means of a lever *u*. This lever is attached to a grooved wheel, in which works a chain attached to the door *t*. The lever attachment is shown in detail at *C*. The chain is fastened to the groove of the wheel with a staple *v*. Power is applied to the lever by means of the rope *w*. The wheel is supported by two 4 in. × 12 in. oak timbers *x*, which are bolted to the plate *y* and the timber *m*, and are so fastened at the top as to project forwards, as shown at *x* in the elevation. This arrangement throws the wheel axis forwards, so that the lifting chain will clear the woodwork.

To take coal, the engineman first lowers the spout *r*; he then pulls down the lever *u* by means of the rope *w*, which raises the door *t* and allows the coal to run from the pocket into the tender. When sufficient coal has been allowed to run out, the pull on the rope *w* is released and the weight of the door *t* causes it to descend. The pocket floor at *z* should not be less than 11 feet above the top of the rail.

In this type of coaling station, the loaded cars of coal are dumped directly from the track above into the pockets. The supply track is usually an inclined plane, with a grade as sharp as is consistent with safe operation. Sometimes, where space is very limited, the loaded cars of coal are hauled to the top of the pockets by cable over a steep incline.

18. More Modern Coaling Stations.—A modern coaling station, in which the coal is handled by machinery, is shown in Fig. 12. The figure includes a general plan of the station, the elevation being shown at *A* and the cross-section at *B*. The power for driving the machinery is furnished by the engine *c*. The machinery consists of an elevator *d d* and a conveyer *e e*, composed of link belts carrying projecting pieces of board, which, as they slide through troughs lined with sheet iron, form elevating or conveying buckets—first elevating the coal from the pocket beneath the track where it is dumped from the car to the head of the incline, and then conveying it to the different pockets, where it is stored ready for the use of locomotives. The link belts are driven

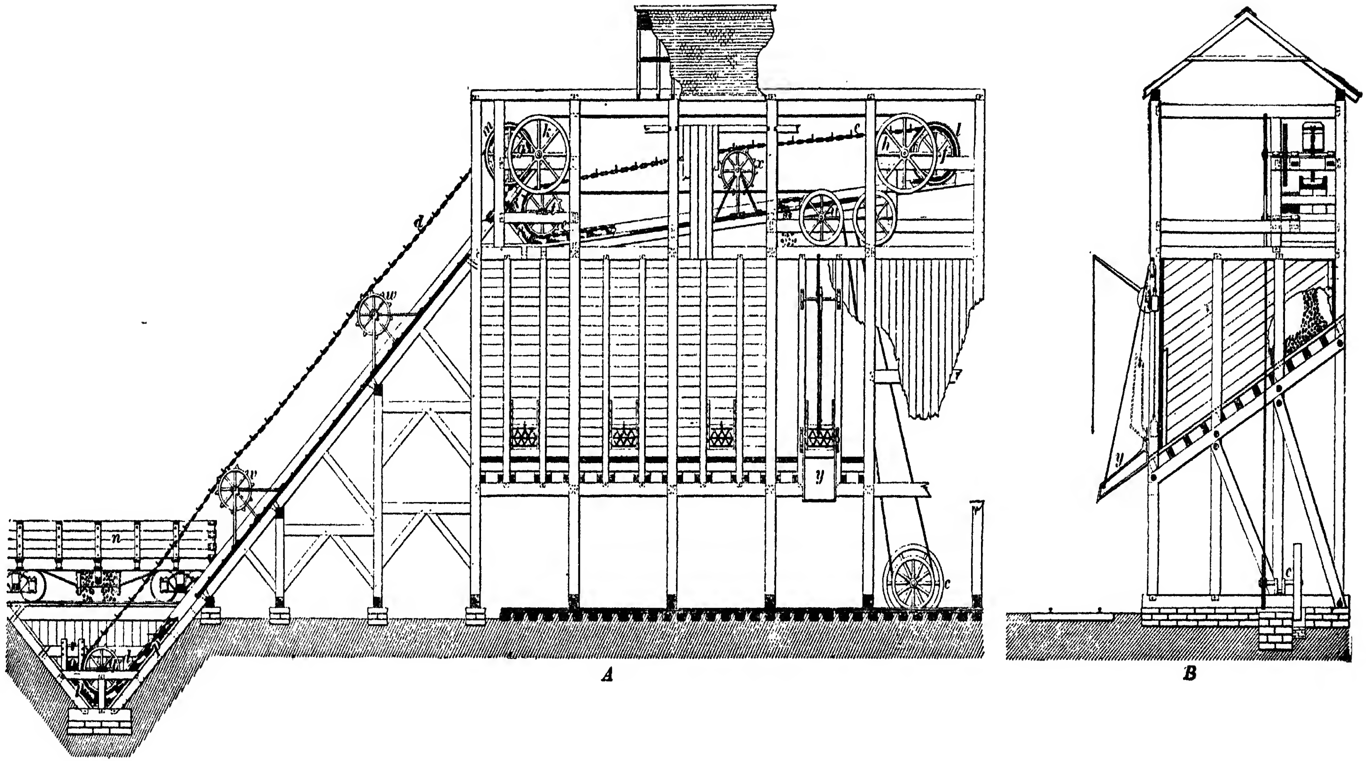


FIG. 12

by sprocket wheels *f* and *g*. The power is transmitted from the engine to the machinery by means of a wire-rope belt. The main sheaves *h* and *k* are 6 feet in diameter. They are attached to shafts carrying pinions that drive the gears *l* and *m*, and, with them, the sprocket wheels *f* and *g*. The coal to be elevated to the coal pockets is first dumped from the car *n* into a chamber beneath the track. The coal runs by gravity from this chamber through the opening *o* into the elevating chute *p*, which is lined with sheet iron; and, as the projecting boards carried by the link belt pass under the sprocket wheel *q*, they push the coal before them, forming a series of buckets, which carry the coal to the point *r*, where an opening in the chute allows the coal to fall into the conveying chute *s*. Here a similar series of buckets passing around the sprocket wheel *t* collect the coal as it falls from the elevator chute and carry it to the storage pockets of the station. In the bottom of the conveying chute, and directly above each pocket, are openings of suitable dimensions, equipped with close-fitting sliding doors and so arranged that every opening is closed except the one that connects with the pocket to be filled. The sheave *u* is fitted with a sliding journal that provides for taking up any slack that stretching may cause in the wire-rope drive. The link belt of the elevator on its return is supported by the sheaves *v* and *w*, and the conveyer belt by the sheave *x*. These sheaves are supported by brackets bolted to the floor timbers of the chutes. The pockets are enclosed with planks and covered with a slate roof, an open space 2 feet in width being left under the eaves for the free circulation of air. The general form of the coal pockets is the same as that of those shown in Fig. 11. The coaling spouts *y*, *y* are made of cast iron instead of plank lined with sheet iron. The spouts are raised and lowered by means of counterweights, as shown both in elevation and cross-section. The pockets are lined with sheet iron or steel. The gauge line of the track is commonly placed 5 feet from the face of the coal pockets, while the bottom of the pockets at their connection with the spouts is located 12 feet above the rail.

At the present time, many coaling stations are manufactured of structural steel and of reinforced concrete. The general arrangement and method of operation of these is the same in principle as that shown in Fig. 12.

TURNTABLES

19. **A turntable,** as shown in Fig. 13, is a platform, usually from 50 to 70 feet long, and from 8 to 10 feet wide, on which a locomotive and tender may be run and then turned horizontally through any portion of a circle, to be transferred from one to another of two tracks inclined to each other. The table is supported by a pivot under its center, and by wheels or rollers under its ends. Beneath the platform is excavated a circular pit 4 or 5 feet deep, having its circumference lined with brick or stone masonry 2 feet in depth and capped with either cut stone or wood. The diameter of the pit in the clear is about 2 inches greater than the length of the turntable. The masonry lining is usually built with a step (see elevation *B*), which supports the rail on which the end rollers travel. At the center of the pit is a substantial foundation of masonry, on which the pivot rests. This foundation should be 4 or 5 feet in depth and be composed of large, regularly shaped stones laid in cement mortar and well bonded together; it is capped by a single stone 6 feet square and 12 inches thick. The pivot, shown in detail at *C*, is fastened to the foundation with heavy anchor bolts reaching the full depth of the masonry. Sometimes, the pit is floored over with plank, but this so greatly increases the weight of the table, besides involving the expense of renewal, that it should be dispensed with unless circumstances make a floor necessary. Usually, only a walk of planks, supported by the projecting ties, is allowed.

The turntable should be somewhat longer than the total length of both locomotive and tender, so as to permit the engineman to move his engine a few feet in either direction from the pivot in order to secure equilibrium. With a little practice, such a condition is easily obtained, so that the

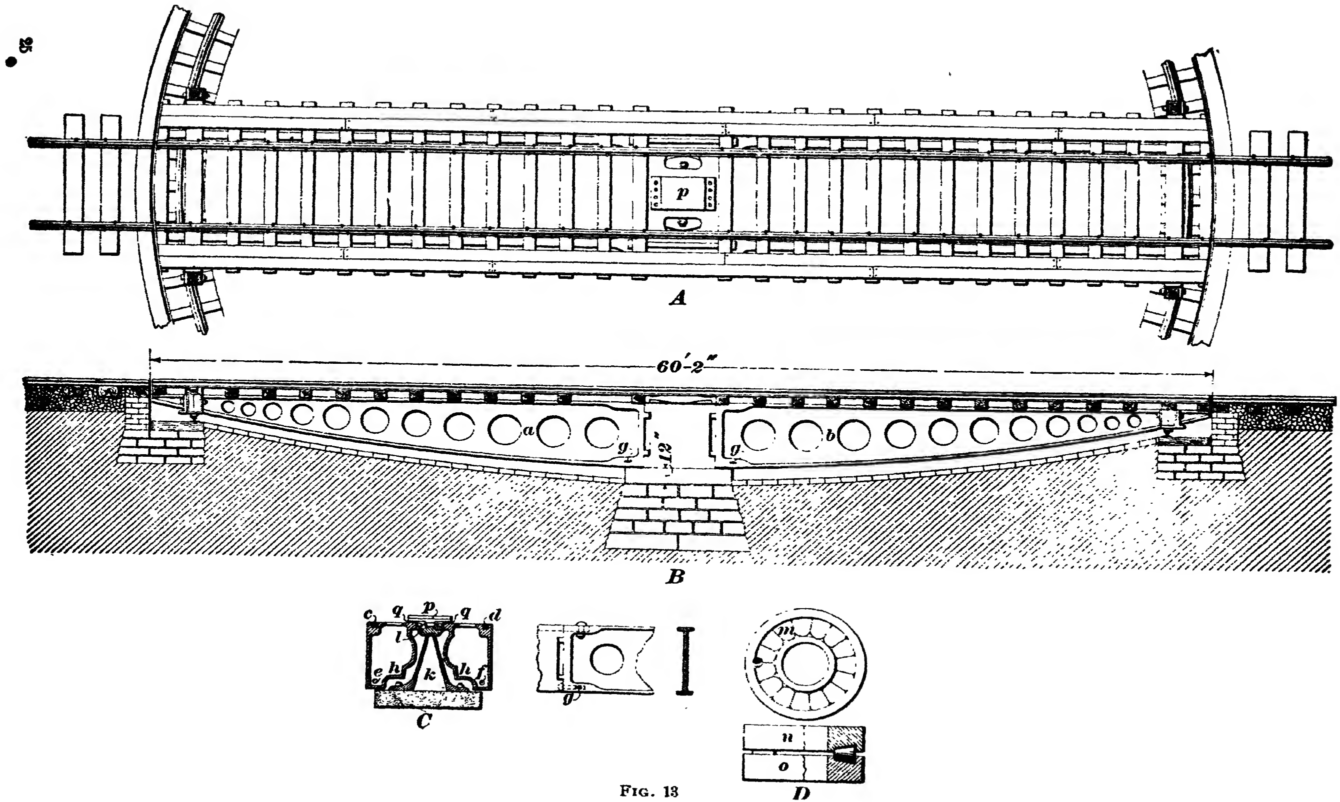


FIG. 13

friction while turning is confined chiefly to the center of motion.

The turntable shown in Fig. 13 is a type of cast-iron table manufactured by Wm. Sellers & Co., of Philadelphia, Pennsylvania. A man can readily turn one of these tables, loaded, without the assistance of machinery. A turntable of this kind consists of two heavy cast-iron girders, perforated by circular holes to reduce weight and cost. Each girder consists of two parts *a* and *b*, fastened to a heavy central boxing, shown in cross-section at *C*. The girders are fastened to the boxing by means of heavy iron bars *c*, *d*, $3\frac{3}{4}$ inches square, of rolled iron, fitted into sunk recesses on top of the boxing, and tightened in place by means of wedges, and also by means of two $2\frac{1}{4}$-inch key bolts at the base of the girders, passing through the holes *e*, *f*, and confined by the keys *g*, *g*. The central portion of the boxing is a hollow cone *h*, open at the top and bottom and surrounding the hollow conical pivot post *k*. The pivot shell is about $1\frac{3}{4}$ inches thick. On top of the post rests a heavy loose cast-iron cap *l*, which permits of a slight rocking motion of the entire platform as the engine enters and leaves the turntable. This cap supports the steel box (see detail *D*) containing the **friction rollers** *m*. There are fifteen of these rollers, each about $2\frac{3}{4}$ inches both in length and in greatest diameter. They have no axles, but lie loosely in the lower part of the box, filling its circumference with the exception of $\frac{1}{2}$ inch of space left for the free movement of the rollers. In the direction of their axes they have but $\frac{1}{8}$ inch play in the box. The lid *n* of the box rests directly on the rollers themselves, and does not come down to the lower part *o* of the box by $\frac{1}{2}$ inch. Both the rollers and the box enclosing them are finished with mathematical accuracy, so as to insure a perfect bearing between them. The rollers are kept constantly oiled, as ease in turning depends entirely on their being well lubricated. On top of the rollers is the cap *p*, which is secured by heavy bolts. This cap does not rest directly on the boxing, but is separated from it by wooden wedges *q*, *q*, by means of which the table may be

raised or lowered and its height exactly adjusted to the connecting track.

When the engine is properly balanced, the cap bolts sustain all the load placed on the turntable, except the small amount carried by the tracks at the end of the platform.

When properly balanced on a Sellers' turntable, the end wheels should only just touch the rails. The diameter of the roller box being 15 inches, it is not difficult to balance the locomotive and tender. All turntables should be provided with means for raising or lowering, and should be so adjusted as to give the proper bearing on the circular track.

FENCES

20. General Design.—It is very important that the posts for fences should be thoroughly seasoned before being used. Since the section men are usually occupied with urgent track repairs during the spring season, fence building is generally deferred until the fall. If the fence posts are cut during the winter season (as they should be), they should be allowed to season thoroughly under cover until

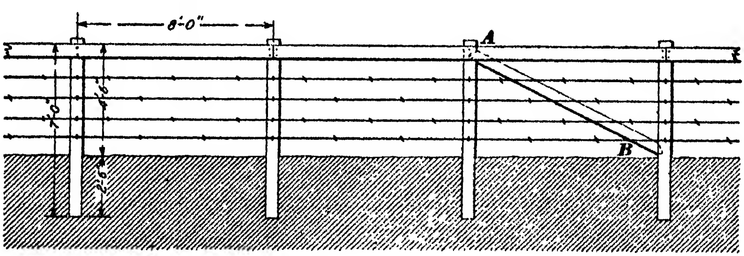


FIG. 14

the following fall. Considering the magnitude of the work of fencing both sides of a railroad line, any reduction in the cost per foot of fence is of considerable financial importance.

Perhaps the most effective and economical fence is that made with four lines of barbed wire and one board at the top, as shown in Fig. 14. Posts are spaced 8 feet between centers and set 2 feet 6 inches into the ground. At

intervals of 500 feet on straight lines, and at every angle, braces *A B* should be built into the fence. The brace is mortised into the post at the top and gained into the post at the bottom. The wires are spaced as follows, beginning at the bottom wire, which is 9 inches above the ground: the first and second wires are 9 inches apart; the second and third, 10 inches; the third and fourth, 10 inches; and the fourth is placed 10 inches from the top board or rail, which is 6 inches in width. This makes the total height of the fence 4 feet 6 inches (which is a lawful height in most of the states), while the total length of the posts is 7 feet.

When barb-wire fences were first introduced, the posts and braces were the only wood material used; such fences proved very injurious to live stock, which, failing to see the wire, continually came in hurtful contact with the barbs. This objection is removed by placing a single board for the top rail. The board clearly marks the fence line, and, together with the barb wire, makes the most effective fence known.

21. Laying Out and Construction.—In laying out a fence, a distance equal to one-half of the right of way is measured from the center line, and a temporary post is set. These posts are placed from 50 to 80 rods apart on tangents, and from 50 to 100 feet apart on curves. A light wire is then stretched between the posts, with tags at intervals of 8 feet, for spacing and lining the posts. A man then takes a spade and plumbs down from each tag with a lining bar, making a mark with its point; he next removes the sod from around the mark. This mark locates the center of a post and guides the men that dig the post holes. The wire is removed while the holes are being dug, and afterwards replaced to give a line for setting the posts. The diggers should be provided with a gauge giving the proper depth of the hole. The men that nail either boards or wire must be provided with a gauge giving the top of the fence and the spacing of each strand of wire.

A handy gauge for spacing wires is shown in Fig. 15. It consists of a foot-piece of pine 2 feet in length, 6 inches

in width, and 1 inch in thickness. Another piece of pine 3 inches wide and 4 feet 6 inches in length, equal to the height of the fence, is nailed to the foot-piece at its middle, as shown in the figure. The spacing of each wire from the ground is marked by a notch cut into the edge of the upright piece. The foot-piece, besides giving the height from the average surface of the ground, helps to keep the gauge in an upright position.

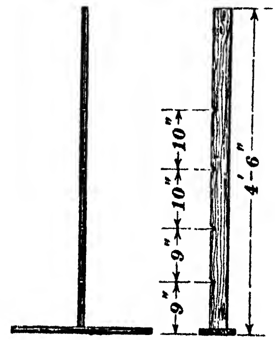


FIG. 15

In building a fence, judgment should be used in distributing the force. With a force of a dozen men, the following distribution is recommended: two men to lay out the work, four to dig holes, three to set posts, and three to nail on boards and string wires.

A wire stretcher is necessary for first-class work and rapid progress, though good work at stretching wire can be done with a crowbar if sufficient care and strength are used.

22. Bracing at Corners.—At highway bridges and culverts, the fence usually turns to the ends of the abutments. The angles made in the fence at these turns must be thoroughly braced. Effective braces are shown in Figs. 16

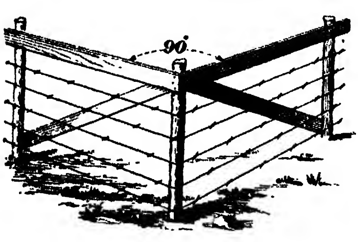


FIG. 16

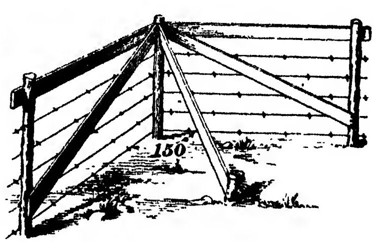


FIG. 17

and 17. In Fig. 16, the angle is 90°, and a brace in each panel abutting on the angle is sufficient. In Fig. 17, where the angle is 150°, an inside brace is added. This brace abuts against a short post set in the ground to receive the

thrust of the brace. Braces must be placed at each opening, such as at farm and road crossings, and at all points where changes in direction require it.

At streams crossed by pile bridges, it is customary to make a turn in the fence on both sides of the stream, and to string the wires across the stream, fastening them to the piles.

On tangents, and on the outside of curves, boards and wire are placed on the farmers' side of the posts, but on the inside of curves are placed on the track side of the line of posts.

23. Material for 1 Mile of Fence.—It will require 660 posts spaced 8 feet between centers to build each mile of fence. One fence board 16 feet long, 6 inches wide, and $1\frac{1}{4}$ inches thick contains 10 feet, board measure, of lumber, and 330, the number of boards required for 1 mile of fence, contains $330 \times 10 = 3{,}300$ feet, board measure.

Barb wire of average weight weighs 1 pound per rod of single wire, or 4 pounds per rod of finished fence. Hence, for 1 mile, or 320 rods, it will require $320 \times 4 = 1{,}280$ pounds. Adding 10 pounds for splices gives 1,290 pounds as the amount of barb wire required for 1 mile of fence. It will require $\frac{1}{8}$ pound of staples for 1 rod of fence, and for 1 mile, or 320 rods, it will require $320 \times \frac{1}{8} = 40$ pounds. These results are tabulated below.

Posts	Boards Feet, B. M.	Barb Wire Pounds	Staples Pounds
660	3,300	1,290	40

24. A Day's Work at Fence Building.—From 12 to 14 rods per man is a fair day's work for fence building, though much depends on the hardness of the ground, the quality of the work, and the skill and industry of the workmen. Fence building requires intelligent industry. A poorly built fence is little better than no fence.

25. Snow Fences.—Snow fences are fences erected to prevent snow blown by the wind from lodging on the track. A snow storm is frequently accompanied by wind. When the velocity of the wind that carries the snow is suddenly

arrested at any point, the snow falls and is deposited in a drift at that point. If a fence is placed across the path of the wind, it will greatly diminish the velocity, and cause the snow to fall partly on the windward side of, and partly a few feet beyond, the fence. This is the usual mechanical principle that is utilized in the construction of snow fences.

Another principle is that the wind may sometimes be made to scour out its own channel through the snow, and literally blow away the snow that is falling or that may have previously fallen, provided that the snow has not yet become wet and heavy. This principle has been utilized by making high board fences on each side of the track, leaving only an opening wide enough for the passage of trains. Through this narrow opening, the wind will scour with so great a velocity that it effectively clears away the snow. This is the only type of snow fence that will be effective when the prevailing snow winds have the same direction as the track.

A rule is sometimes given that a snow fence should be 12 feet away from the track for each foot of its height. Such a rule is necessarily approximate and may lead to excessive results. According to it, a 6-foot fence should be placed 72 feet from the track. The right of way is frequently not sufficiently wide to satisfy these conditions, and this would require the erection of the fence on the adjoining property. Sometimes, the fences are made in such a manner that they are readily portable and therefore may be set upon the adjoining property early in the winter, when they will not be objectionable, and may be removed in the spring, before the land is needed for cultivation. When drifts form to an excessive height, portable fences are sometimes placed at the top of a drift, in order to further protect the track from the snow. Such fences are made with boards, which must be placed close together, although the cracks may be made 1 inch or more in width. Fences of this nature are only needed in special places, and are usually placed so that they are at right angles to the prevailing direction of the snow winds, which usually come from the northwest, north, or northeast.

26. Snow Sheds.—The protection of the track by means of snow sheds is, in general, required only in localities where the track is subject either to very heavy snowfalls or to avalanches of snow, which often are accompanied with rocks and earth. Considering that a road running through a very narrow valley between two high mountains may be choked by an avalanche and be blocked for the remainder of the winter, such a construction, although very expensive, is justifiable. Since the snow shed must withstand the weight and impact of heavy masses of snow, earth, and rocks, it must have very great strength.

A snow shed is usually made of bents, with the same kind of timber that is used in trestle work, the bents being placed as close together as the circumstances appear to justify. This may mean as close as 3 feet. The bents are of the same general construction as the wooden timbering for a tunnel, and are suitably braced with longitudinal bracing and boarded on the outside. Usually, the boards are omitted on the side wall for a width of about 2 feet immediately below the eaves of the roof; this is to allow for ventilation and to give light in the shed. Since the passage of a train through such a shed is almost as objectionable as running through a tunnel, some roads have what they call a "summer track," which is outside of the snow shed and may be used in clear weather and when there is no snow.

Usually, the earth is purposely piled up above the top of the snow shed on the uphill side, so that any avalanche of snow or earth that may come down the hillside will be deflected by the shed and therefore spend its impact on the ground beyond rather than on the shed.

The danger of destruction of snow sheds by fire during the dry summer season is very great. By constructing the sheds in sections, with a break of about 100 feet between each two sections, a fire in any one section can usually be confined to that section. When such construction is adopted, the part of the road between sections is protected by Y-shaped deflectors, which are placed on the uphill side and deflect toward the shed any avalanche that may come down on them.

FREIGHT YARDS

27. Advantages of a Good Design.—It is only in recent years that the true principles of the construction of freight yards have been recognized. Nearly all the older freight yards were constructed with little or no design or provision for future growth. The result has been that railroads have been generally compelled to reconstruct entirely their yards. It is now realized that a freight yard must be considered as a huge machine for the classification and redistribution of freight cars, and that a design that will most quickly and with a minimum amount of shifting receive the cars and send them out in their several directions is the most economical machine. Any large freight yard requires the constant use of several switching engines. The cost of an engine of this kind—taking into consideration the wages of the engineman and fireman, the cost of fuel and other engine supplies, the cost of engine repairs, and the amount properly assignable to capitalization and deterioration—will amount to about $25 a day. Assuming that the engine is only used on weekdays, the annual cost amounts to $7,825, which is the interest, at 5 per cent., on $156,500. If a yard can be rebuilt in such a way that the services of even one switching engine can be dispensed with, the saving will in most cases justify the expenditure of reconstruction.

It is not always possible to make an ideal yard, since the necessity for having a yard at or near some large city may require that the yard should be located in the best place obtainable, and this may mean a locality where the topography is such that the yard cannot have the most desirable shape and arrangement. But even then it is possible to follow certain fundamental principles.

28. Ideal Design of a Freight Yard.—In Fig. 18 is shown an ideal type of general freight yard recommended by the American Railway Engineering and Maintenance of Way Association. In order that the figure might be placed on one page it was necessary to cut it in two parts; these two parts

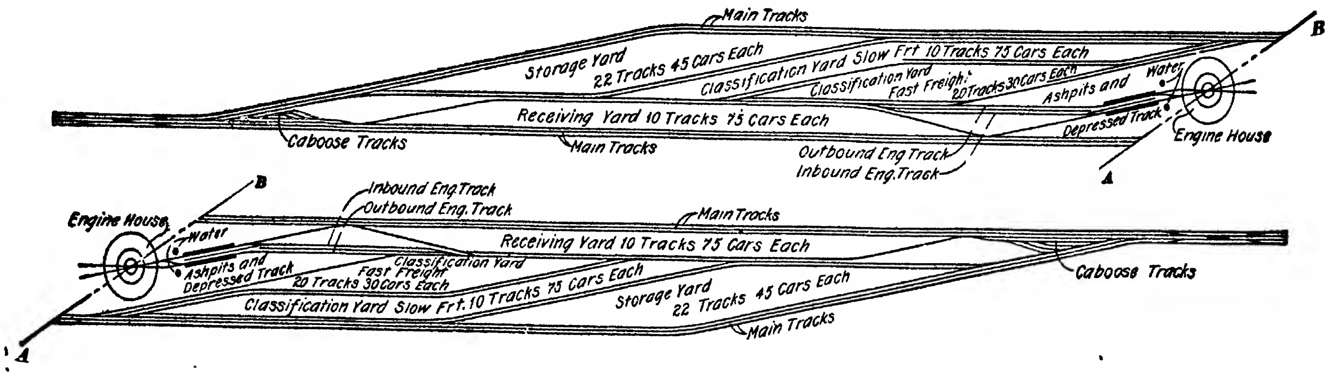

Main Tracks
B
Storage Yard
22 Tracks 45 Cars Each
Classification Yard Slow Frt 10 Tracks 75 Cars Each
Classification Yard
Fast Freight
20 Tracks 30 Cars Each
Ashpits and
Water
Receiving Yard 10 Tracks 75 Cars Each
Depressed Track
Engine House
Caboose Tracks
Main Tracks
Outbound Eng Track
Inbound Eng. Track
A
B
Inbound Eng. Track
Outbound Eng. Track
Engine House
Water
Main Tracks
Receiving Yard 10 Tracks 75 Cars Each
Ashpits and
Depressed Track
Classification Yard
Fast Freight
20 Tracks 30 Cars Each
Caboose Tracks
Classification Yard Slow Frt. 10 Tracks 75 Cars Each
Storage Yard
22 Tracks 45 Cars Each
Main Tracks
A

FIG. 18

are supposed to be joined along the line $A B$, with respect to which the two parts are symmetrical. In this design, each track, or pair of rails, is indicated by a single line. The storage tracks have not been drawn in. Their direction is indicated by the direction of the lettering that describes them. The lines that are shown represent the tracks on which cars should not be stored and should not be allowed to stand long. Fig. 18 may be called a skeleton of the yard. It is easier to study the general principles of a freight yard from such a skeleton than from the full detailed drawing. This figure should be constantly referred to in connection with the explanations that follow, although these explanations are of a general character.

1. There must be one or more **receiving tracks** into which a freight train may turn from the main track and where it may wait without interfering with yard operations until the switching engines may commence the work of distribution. The receiving yard in Fig. 18 has ten tracks capable of holding seventy-five cars each.

2. If the yard is at the end of a division of the road, the engine will usually be changed, even though the train is a through freight train that is to be forwarded unbroken over the next division of the road. In such a case, the engine is detached and proceeds to the engine yard, where it unloads its accumulation of ashes into the ash-pit and takes on a new supply of coal, water, sand, and other engine supplies. In Fig. 18 is shown how the engine may run from the receiving track to the tracks where it obtains its supplies, and if necessary go into the roundhouse without interfering with the other work of the yard. Sometimes, even the caboose is changed, and, if so, it is detached from the rear of the train and placed on one of the caboose tracks, where it waits its turn to be attached to an outgoing train running back on the same division.

3. A switching engine then draws the train out to the classification yard and distributes the cars to various tracks according to their destination. For example, some cars may need to be sent to the local freight yard for unloading; some

cars may be empties and are to be sent to some local freight yard, where they are needed to be loaded up. A freight yard usually has a few tracks for the temporary storage of "cripples," which are cars that need some slight temporary repairs in order that they may finish their trip before being unloaded and subjected to a general overhauling.

4. The tracks at each end of a group of storage tracks usually make the same angle with the storage tracks and are connected by switches that have the same frog angle. The tracks at the end of the storage tracks are called **ladder tracks.** Frequently, the ladder track makes an angle with the storage tracks that is equal to the frog angle used in all switches. In such a case, there is no connecting curve beyond the frog, but the straight track runs out in the direction given by the frog rail. By making the storage tracks double-ended, cars may be drawn from either end without disturbing cars that are not needed. If the two ladder tracks at each end of a series of storage tracks make the same angle with the storage tracks, that particular section of the yard will have the form of a parallelogram. This is illustrated in Fig. 18.

5. A device that permits a single switching engine to do a greater amount of work and handle more cars in a given time is to regrade, as much as necessary, the entire yard, so that there is a grade of about .5 per cent. in the direction in which cars are shifted in distributing them to the various tracks. Such a grade will overcome a tractive resistance of 10 pounds per ton, and this is sufficient to keep a car moving after it has been started by the switching engine. The engineer of the switching train may therefore start each car with a "kick" from the engine. By carefully operating the switches, the car may be made to move down the ladder track and on to the desired storage track, where it is stopped by the use of hand-brakes. A brakeman should accompany each car or group of cars.

6. The frog angle for a series of tracks running off from the ladder track should be the same. No. 6 or No. 7 frogs are very commonly used for this work. Sharper frog angles

give easier riding and possibly less danger of derailment, but the length of the lead for each turnout is then considerably greater, and the available space for the storage of cars is correspondingly reduced. No. 5 frogs give still greater space for storage tracks, but the frog angles are so blunt that the danger of derailment is great, unless the switching is done more slowly and carefully than is economical.

7. Corresponding with the receiving tracks, **departing tracks** are usually provided, on which a train that has been assembled and is ready to start may wait until the proper time to send it out. Fig. 18 does not indicate any special tracks for this purpose. With the arrangement shown in that figure, the tracks of the receiving yard would probably be utilized for this purpose.

29. Connection of Yard With Main Tracks.—Safety requires that the main tracks be kept as separate as possible from the yard tracks. It will be noticed in Fig. 18 that there is no connection between the two pair of main tracks that surround the yard and the yard tracks, except by a series of switches at the extreme ends of the yard. Such switches would of course be amply protected by signals. Under no conditions should any main track be used as a ladder track from which to run out numerous switches. Even in the case of the sidings required at a very small local station, it is desirable to have the various sidings that connect with manufacturing establishments run off from a track that is itself a siding and is connected with the main track by a single switch.

30. Minor Freight Yards.—It is not only of advantage to shippers, but also to a railroad company, that minor freight yards should be established in different sections of all large cities, especially those which have a water front. The cars are sent to these yards either by long sidings, which often run through the city streets, or by means of floats, which can transport a large number of freight cars and land them at freight yards on the water front. Such freight yards are always necessarily located on land that is very expensive

and that must therefore be utilized to the utmost. In order to accommodate a large number of cars in a plot of ground whose form is already determined, and which probably is not of the most convenient shape, it will usually be necessary that all switches in the yard shall have very blunt frog angles and that the curves shall be very sharp. Sometimes, the radius of curvature is made as small as 50 feet, although such curves are very troublesome, since the ends of 40-foot freight cars will make a very considerable angle with each other on such curves. This will require the ordinary couplers between cars or between an engine and a car to be replaced with a **bar coupler,** which is a heavy flat bar of iron, about 3 feet long, fastened to an ordinary coupler by means of the old-fashioned link pin. If the curve can be allowed a radius of at least 150 feet, there will usually be no trouble in shifting cars on such curves.

A minor freight yard is always provided with **team tracks.** These are single-ended tracks placed on the outskirts of the yard, usually in pairs, with a clear space of about 15 feet between pairs, so as to permit teams to be driven alongside the cars for the purpose of loading or unloading.

31. Appliances for Loading and Unloading.—A great convenience, or even a necessity in some yards, is a traveling crane with which single pieces of freight weighing several tons may be transferred from a truck to a car, or vice versa. An ordinary gin pole may be utilized for a load under 8,000 or 10,000 pounds. A more convenient form is a crane with a traveler that can pick up a load and move with it along a fixed runway so as to place it over the car or wagon. This runway should have a length equal at least to the space required for one track and for one wagon to stand beside it. Another form is a crane that not only has a traveler but can be moved on rails that are parallel with the tracks. This arrangement permits the crane to pick up its load and move with it not only laterally to the tracks, but also parallel with them.

32. Track Scales.—Freight that is shipped by the carload is usually weighed by weighing the loaded car and deducting the weight of the car itself to obtain the net load. The weight of the car is most readily determined by **track scales.** These are platform scales having a pair of rails on the platform, the scales being located on the line of one of the switch tracks. With quick skilful work, it is possible to weigh all the cars of the train while they are moving over the scales with a very slow velocity. In order to relieve the scale mechanism of the stresses that would come on it by having all the cars that pass over that switch running over the scale platform, it is usual to place point switches about 20 feet from each end of the scale platform, and to run a pair of parallel rails, spaced 8 to 10 inches from the scale rails, which run over the platform. One of these rails lies on the fixed wall immediately outside of the platform; the other rests on columns that are supported on the bottom of the platform pit and come up through holes in the platform, the distance between these columns being about 3 feet. The rail can readily support the weight on one car wheel on a span of 3 feet, and therefore, when a car runs over this pair of rails, its weight is not carried by the scale platform. The switches are ordinarily set for the fixed tracks, and the cars run on the platform rails only when they are to be weighed.

CATTLE GUARDS

33. Requirements of Cattle Guards.—The presence of cattle on a railroad track not only implies a loss to the owner of the cattle, but also the likelihood of a suit for damages against the railroad company, as well as the possible derailment of a train. Fencing can ordinarily be relied on to keep from the track any cattle that are in adjoining fields; but when the railroad is crossed by a highway, cattle that may be straying along the highway are apt to turn down the railroad track. It is therefore necessary to employ some device that will prevent cattle from moving along the railroad track and yet leave the track safe at all

times. The following discussion will show how difficult it is to accomplish effectually these two objects at the same time.

34. Open-Pit Cattle Guards.—An **open-pit cattle guard** consists essentially of a pit 3 or 4 feet deep, about 9 feet long (across the track), for a single-track road, and about 3 feet wide (in the direction of the road). The pit is spanned by some form of girder, which is usually a wooden stringer to support each rail. Wing fences, described later, are built from the sides of the right of way up to each end of the pit.

Cattle guards of this kind are very effective for turning cattle away, but they often cause trouble owing to cattle falling into them and obstructing the track by projecting above the top sufficiently to be struck by the train and even to cause a derailment. Open-pit cattle guards have usually been constructed by placing a wooden stringer under each rail and resting these stringers on two cross-walls, which are frequently made by piling up three or four heavy timbers. Such a structure is not only subject to decay, but is frequently burned by hot cinders falling from the locomotive. The burning may not be sufficient to be noticed, and on this account is all the more dangerous. Even if the structure is substantially built and frequently and thoroughly inspected, there is still the great danger that a car may become derailed very near the pit and a serious train wreck result.

This form of cattle guard has been abandoned on all first-class roads.

35. Covered-Pit Guards.—The **covered-pit guard**, which also has been abandoned by all good roads, differs from the form just described in being partly covered on top by wooden ties placed at short intervals. Its only possible advantage is that it effectually prevents cattle from crossing; but cattle frequently attempt to cross and merely get hopelessly entangled by falling partly through the guard. The danger of destruction by fire or of yielding to the weight of trains on account of decay is as great as with open pits. The covered pit has the one advantage over the open pit

that, if a car becomes derailed, the wheels will roll over the covering ties, and the danger of a serious train wreck is materially reduced. In this method of construction, the ties are chamfered on their upper corners so that there is no broad flat surface exposed on which cattle may place their feet so as to walk over it.

36. Surface Cattle Guards.—At present, **surface cattle guards**, in some of their multitudinous varieties, are exclusively used on all first-class roads. Although they are not so effective in turning away cattle, they have the very great advantage that they do not make an unsafe place in the roadbed. Ties supported by ballast are the same under these cattle guards as at any other place in the road. Some of the other advantages of these guards are their low first cost, which is less than that of either of the other two forms described above; that they can be put in with ordinary track labor; and that they can be easily taken up and replaced when track repairs are necessary.

In this form of guard, something on which cattle will not attempt to walk is placed on the track: such is the essential principle. A convenient device is to place on the track wooden slats with a clear spacing of 1 or 2 inches and with chamfered upper edges, as shown in detail in Fig. 19.

Sometimes, the slats are made of thin plates of iron having perhaps a saw-tooth edge, the thin edge being placed vertical. If a cow attempts to step on such a structure, the sharp edge of the iron will hurt her foot and cause her to draw back before taking another step. Another form of slat consists of a vitrified tile, which is made in pieces about 15 inches long. The top of the tile forms a sharp edge, and, by placing the tiles end to end, a slat of any length can be made. The advantages claimed for these slats are that they are free from decay, and that they are not readily broken. Even if a few become broken, they can be readily replaced without renewing the whole structure.

The length (parallel with the track) of a surface cattle guard is about 8 feet. Of course, the guard must cover

the entire width between the rails, and also a width of about 2½ feet outside of the rails, so as to give clearance room for the rolling stock.

An additional element of effectiveness to a cattle guard is obtained by painting the whole structure white. This helps

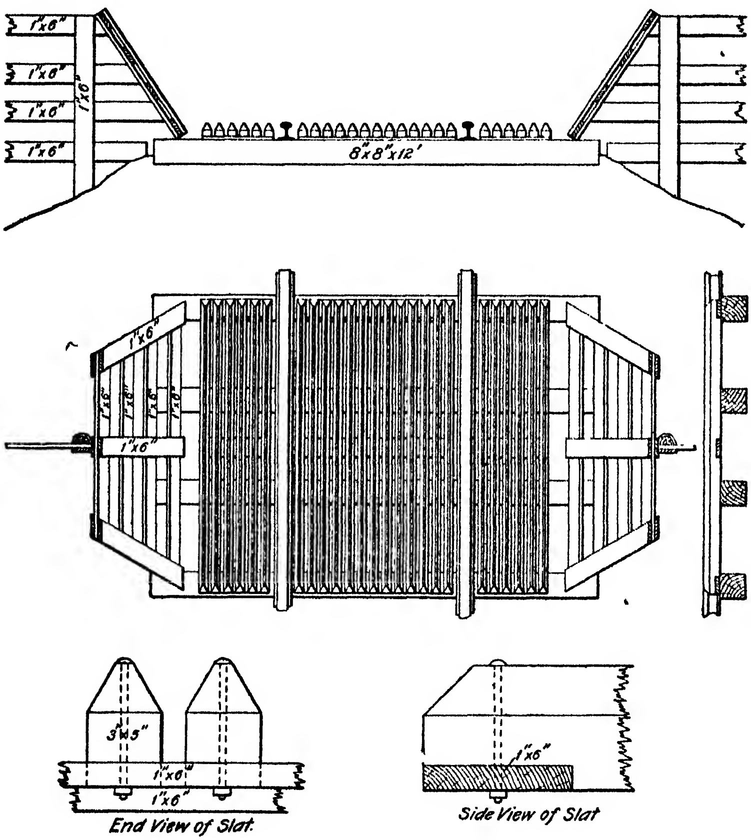


FIG. 19

to turn cattle away. Sometimes, when cattle get on the track and a train comes along, they will run blindly down the track instead of getting off out of the way of the train. If they reach a cattle guard painted white, the sight of the white surface on the track will startle them and frequently cause them to turn to one side.

ASH-PITS AND CARS

37. General Requirements for Ash-Pits.—An **ash-pit** is essentially a depression between the rails in which a considerable amount of ashes may be dumped from the fire-box of the engine without danger that the deposit will accumulate to a higher level than that of the rails and thereby form an obstruction in the track. It is of course impracticable to have such a pit obstructed by cross-ties, and therefore the rails are laid on stringers, which usually consist of 10 in. × 10 in. timbers of yellow pine. To render the process of removing the ashes less difficult, the pit should have a hard smooth bottom, such as may be readily made with concrete. The bottom should also be unaffected by the cinders, which frequently contain a considerable proportion of live coal. This precludes the use of a wooden lining for the pit. In order to prevent water from accumulating in these pits and becoming stagnant, the bottom of the pit should have a sufficient slope to drain off any water to a low point in the pit, from which a terra-cotta pipe drain leads the water to a suitable outfall. The side walls of the pit should also be smooth and unaffected by live coals, and should have such structural stiffness that the wooden stringers and the rails will be kept rigidly in line, and the gauge of the track properly maintained. The side walls are usually made of concrete, although brick and stone are often used.

38. Engine-House Ash-Pits.—The general requirements for an ash-pit in an engine house are the same as those just given, except that the flooring is usually built to the level of the top of the rail on the outer side of each rail. Since an engine-house ash-pit will usually not be required to contain the deposits from numerous engines without being cleaned out, it need not be made of such capacity as the ash-pits ordinarily found in yards. In Fig. 20 is shown the design of ash-pits built for an engine house at the Baldwin Locomotive Works, Philadelphia, Pennsylvania. This design

should be studied in connection with the statement of general requirements given in Art. **37.**

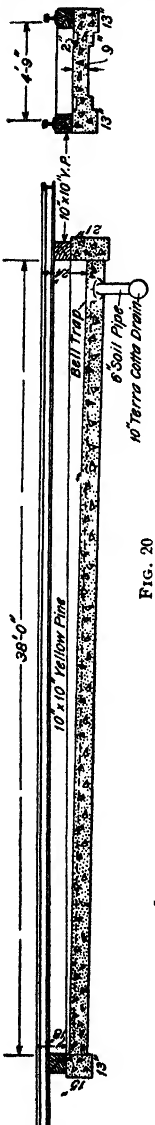


FIG. 20

39. Yard Ash-Pits.—A yard pit has the same general design as is shown in Fig. 20, except that the pit may be constructed somewhat deeper; and, if so, the side walls should be made correspondingly thicker, so that they can withstand any possible thrust from the outside earth. Sometimes, as a further precaution to the side walls, they are covered with plates of sheet iron. Although concrete will withstand successfully a very considerable degree of heat, yet, if a mass of red-hot coal is dropped on it, the outer layer of the concrete will be calcined and will gradually be worn off, especially if cold water is thrown in to quench the coals. On this account, the use of concrete is sometimes discarded, and the side walls are built of brick, the bottom being lined with a brick that approaches firebrick in its qualities.

40. Depressed Tracks for Cinder Cars. The pits just described are only the simplest forms of ash-pits, from which ashes must be removed by shoveling. The method of ash disposal indicated in Fig. 18 consists in making a depressed track, on which a gondola car is run, so that the level of the top of the car is considerably below that of an adjoining track on which the engine is run. In Fig. 18, the depressed track is placed between a pair of tracks. The ashes from the engine firebox are then dumped into a chute, which carries them under the girder supporting the rail and delivers them directly into the ash car on the depressed track. Since it is easier to haul a car of ashes out of a pit than to require each engine to climb

to an elevated structure, the method of using a depressed track for the cinder car is preferable to that of building a trestle for the engine to climb.

41. Ash Conveyers.—Although the device of a depressed track for a cinder car is far more economical in its operation than the method of handling cinders by shoveling, it is still more economical, when the magnitude of the work will justify it, to remove the ashes from the engine to a cinder car by means of a conveyer, which is very similar in its operation to that of a coal conveyer. Frequently, a coaling station is equipped with a conveyer for ashes, since it not only economizes in the cost of maintaining the plant, but also enables an engine to discharge its accumulation of ashes and to replenish the tender with coal at the same time, and therefore save time for the engine. Since the general method of operation of such a conveyer plant is similar to that of the coaling station described in Art. 18, it will not be further described except to refer to the very obvious difference that the ashes are dropped from the under side of the engine on to the conveyer belt and thence carried upwards until they are dumped into the cinder car, which is conveniently placed for this purpose.

HIGHWAYS

(PART 1)

GENERAL CONSIDERATIONS

1. Office of Highways.—**Highways,** or **roads,** may be defined as lines of communication passing through the country and connecting the farms and villages with the towns and cities, thus affording a market for the produce of the fields and an outlet for the manufactured goods of the cities. Through them, the natural resources of the country are developed and industry and commerce are promoted.

Roads are of various kinds, according to the wealth and character of the country traversed; they range from the natural-earth surface to the most modern paved structure.

The object of road construction and improvement is to furnish a pathway over which the traffic may be carried on with a minimum expenditure of motive power, consistent with reasonable economy in the cost of construction and maintenance. To attain this end, certain essential conditions must be taken into account.

2. Requisites for a Good Road.—In order that a road may be satisfactory for travel, it must be *dry* and *solid*, and have *easy grades*, *easy curves*, and a *smooth surface*. These conditions refer to the use of the road, but there are other conditions that are essential to economic construction and maintenance; namely, (1) that the length of the road shall be a minimum; (2) that its surface shall be so placed with reference to the natural surface of the ground that the amount of excavation and embankment shall be a minimum;

and (3) that it shall be so located as to be free from landslides, washouts, and snowdrifts. These different conditions often conflict with one another, and there is generally a great deal of difficulty in reconciling them. The question of cost frequently becomes the controlling factor, but it is not always wise to cut down initial cost to the lowest amount possible; such apparent economy may result in the construction of a road requiring for its maintenance much trouble and expense, which might have been avoided by a small extra cost in the original construction. A better plan, and one that should always be followed, is to arrange the road so that future improvements can be made.

3. Advantages of Good Roads.—Good roads promote the development of agricultural, commercial, and manufacturing industries, by reason of: (1) the facility they offer for intercourse at all seasons of the year; (2) the decrease in the cost of transportation; and (3) the opportunities they afford of selecting the most advantageous time and place for marketing the crops. Good roads also aid in improving the social and intellectual condition of the rural population, by facilitating intercourse between it and the urban populations. Besides, by facilitating travel, good roads attract population to the country districts, and thus increase the value of land.

4. Cost of Wagon Transportation.—The cost of transporting goods and produce by horses and wagons depends on the condition of the road over which the goods are moved: if the surface is rough or the grades steep, the weight of the load a horse can draw is decreased, thus necessitating the making of more trips, or the employment of more horses and vehicles to move a given weight. A defective road increases the wear and tear of horses, thereby decreasing their life service and lessening the value of their current services; it also increases the cost of maintaining vehicles and harness.

The average cost of moving a load of 1 ton a distance of 1 mile on level roadways is: for dry, hard earth roads, 18 cents; for earth roads covered with mud and ruts,

26 cents; for loose-gravel roads, 51 cents; for wet-sand roads, 32 cents; for dry-sand roads, 64 cents; for broken-stone roads, dry and in good condition, 8 cents; and for broken-stone roads, covered with mud and ruts, 26 cents. A comparison of these costs clearly shows the advantages of a good, well-kept road.

TRACTION AND GRADIENTS

RESISTANCE TO TRACTION

5. The forces that offer resistance to the motion of vehicles on roads are:

1. **Friction**, which comprises (*a*) friction of the axles, and (*b*) friction between the wheel tires and the surface of the road. The latter form is termed **rolling friction**.
2. **Air resistance**, which includes both the friction caused by the air and the direct resistance that the air offers to displacement.
3. **Gravity**, which comprises (*a*) the resistance due to the grade or inclination of the road, and (*b*) collision, or the resistance offered by obstacles on the surface of the road.

FRICTION AND AIR RESISTANCE

6. Axle Friction.—The resistance arising from the friction of the axles depends on the magnitude of the load, the area of the bearing surface of the axle, and the nature and degree of lubrication. It is entirely independent of the condition of the road surface. With wheels of ordinary construction, it amounts to from $\frac{1}{130}$ to $\frac{1}{100}$ of the weight on the axle.

7. Air Resistance.—The resistance offered by the air varies according to the velocity and direction of the wind, the area of the surface acted on, and the velocity of the vehicle. The pressure of the wind at a velocity of 15 miles an hour, which corresponds to a pleasant breeze, is equal to

about 1 pound per square foot; at a velocity of 50 miles an hour, which is equivalent to a violent storm, it is equal to about 12 pounds per square foot.

8. As axle friction and the resistance of the air are constant and entirely independent of the condition of the road, their effects may be, and usually are, neglected in the construction of roads.

9. Rolling Friction.—Resistance to rolling is divided into two classes: (1) friction arising from the mere contact of the wheel tire with the surface of the road; and (2) friction caused by a lack of strength in the road and its foundation. The latter form of friction is termed **friction or resistance of penetration.** The first form will here be called **rolling friction proper.**

10. Rolling Friction Proper.—The resistance arising from the mere contact between the road surface and the wheel tire varies according to the character of the road surface, the width of the tire, and the diameter of the wheel, and can be determined only by experiment in each particular case.

Numerous experiments have been made to determine the rolling friction offered by a load hauled on various road surfaces. The results, which are shown in Table I, vary through a wide range, as is to be expected when the many different conditions that may affect them are taken into consideration. This table has been compiled from various sources, and is believed to represent fairly the results of the experiments that have been made; it gives the approximate maximum, minimum, and mean rolling friction in pounds, caused by a load of 1 gross ton (2,240 pounds) hauled at an ordinary pace on level road surfaces of the kinds named, and also the mean friction in fractional parts of the load.

The force t required to overcome the total frictional resistance on a level road is given by the general formula

$$t = c W$$

in which W = load moved;

c = value given in the last column of Table I for the various kinds of road surfaces.

The force t and the load W should be expressed in terms of the same unit, as the pound or the ton. The constant c is called the **coefficient of rolling friction.**

TABLE I

ROLLING FRICTION FOR DIFFERENT ROADWAY SURFACES

Character of Roadway Surface	Rolling Friction			
	In Pounds per Gross Ton			Mean In Terms of Load Values of c
	Maximum	Minimum	Mean	
Earth, ordinary	300	125	200	$\frac{1}{11}$
Earth, dry and hard	125	75	100	$\frac{1}{22}$
Gravel, common	147	140	143	$\frac{1}{16}$
Gravel, hard rolled			75	$\frac{1}{30}$
Macadam, ordinary	140	60	90	$\frac{1}{25}$
Macadam, good	80	41	60	$\frac{1}{37}$
Macadam, best	64	30	50	$\frac{1}{45}$
Cobblestone, ordinary			140	$\frac{1}{16}$
Cobblestone, good			75	$\frac{1}{30}$
Granite block, ordinary			90	$\frac{1}{25}$
Granite block, good	80	45	56	$\frac{1}{40}$
Granite block, best	40	25	34	$\frac{1}{66}$
Belgian block, ordinary			56	$\frac{1}{40}$
Belgian block, good	50	26	38	$\frac{1}{60}$
Plank	56	32	44	$\frac{1}{50}$
Wooden block, in good condition	40	20	30	$\frac{1}{75}$
Asphalt	39	15	22	$\frac{1}{100}$

11. The resistance to rolling varies inversely as some function of the diameter of the wheel; it is less for large than for small wheels. Some experiments indicate that it is inversely proportional to the diameter; others indicate that it is inversely proportional to the square root of the diameter; while from mathematical investigation it has been concluded

that it is inversely proportional to the cube root of the diameter. The last conclusion is probably the most nearly correct. If this is the case, the resistance of a wheel of a certain diameter will be to that of a wheel of one-half the diameter as $\sqrt[3]{.5}$ is to $\sqrt[3]{1}$, or as 1 : 1.26, nearly, which is not a very great difference.

As the variation in the size of the wheels on ordinary road vehicles is not very great, this condition may generally be neglected, and for practical purposes the resistance may be taken equal to the load multiplied by the coefficient corresponding to the nature and condition of the road surface.

12. The resistance to rolling is, under some conditions, affected by the width of the wheel tire. On hard and incompressible surfaces, the resistance is practically independent of the width of the tire; while on soft, compressible surfaces the resistance decreases as the width of the tire increases, except when the surface is composed of deep sticky mud that adheres to the wheel, in which case a narrow tire causes less resistance.

Many tests have been made to determine the best width of tire and the proper load for a given width of tire. The results have been different, but they all indicate that to make the tire wider than 6 inches does not diminish the force required to move the load, and unnecessarily increases the dead weight of the vehicles; and that a width of less than 2 inches causes the wheels to cut into the road surface and form ruts that each succeeding vehicle deepens.

The best width of tire will depend on the weight of the load and on the character and condition of the roadway surface; as these vary greatly, no general rule can be stated for the width of tire that will be entirely satisfactory. Perhaps a near approach to a satisfactory general rule for the width of tire would be as follows:

Rule.—*The tires of all freight wagons should have a width of not less than 1 inch for each 1,200 pounds of total load on four wheels, or 300 pounds on each wheel, with a minimum width of $2\frac{1}{2}$ inches.*

Thus, for a four-wheel wagon carrying a load of 3 net tons, or 6,000 pounds, the width of the tire should not be less than $6{,}000 \div 1{,}200 = 5$ inches.

13. The resistance to rolling is materially decreased by the use of springs on the vehicles; they diminish the concussions due to the roughness of the road surface, and diminish also the wear on the road.

14. It has been ascertained by experiment that the resistance to rolling sometimes increases with the velocity, the increments of frictional resistance being directly proportional to the increments of velocity for velocities higher than about 3.3 feet per second, or $2\frac{1}{4}$ miles per hour. This increase is less for vehicles with springs than for those without springs, and is less for smooth road surfaces than for rough ones. On soft roads, the resistance is independent of the velocity.

15. Friction of Penetration.—The friction of penetration is produced by a weak or yielding road—that is, one on which the wheel sinks or penetrates below the surface, leaving a track or rut behind it, and forming a hollow or cavity under it, up which the load has to be lifted, as indicated in Fig. 1. The wheel is thus continuously climbing a slight inclination, or, more correctly, is constantly compressing new material. The resistance due to penetration is less for large than for small wheels, and is measured by the force that, applied horizontally at the axle, is necessary to pull the load up the inclined surface. The magnitude of this force varies with the diameter of the wheel, the width of the tire, the speed, the presence or absence of springs, and the nature of the road surface. If the surface of the road is soft sticky clay, or loose sand or gravel, the force required will be increased considerably by the friction on the submerged sides of the wheel. This frictional resistance is approximately equal to the product of the load by one-third of the semichord of the submerged arc of the wheel, divided by the radius of the wheel.

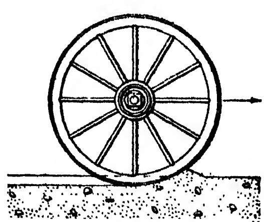


FIG. 1

RESISTANCE OF GRAVITY

16. **Grade resistance** is due to the grade of the road —that is, to the longitudinal inclination of the roadway to the horizontal. It is the same on both good and bad roads, and, unlike the resistances previously described, can be determined exactly from the laws of mechanics.

Fig. 2 represents a wheel on an inclined plane BC, whose inclination to the horizontal is the angle $ACB = x$. The weight on the axle c is w, represented graphically by the line cb. According to the principle of the parallelogram of

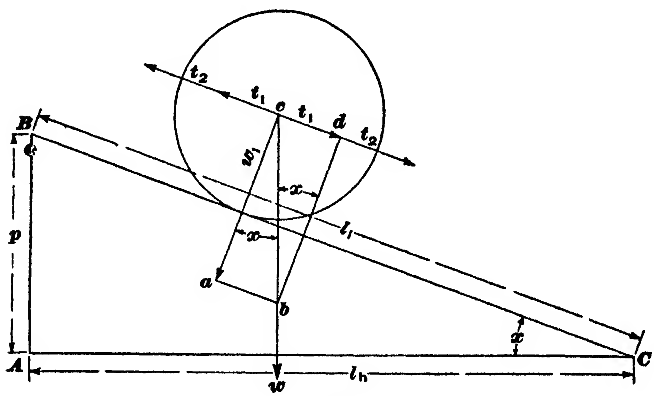


FIG. 2

forces, the weight w may be resolved into the two forces $ca = w_1$ and $cd = t_1$, the former perpendicular, the latter parallel, to BC. The angles acb and cbd are each equal to ACB, their sides being perpendicular to the sides of ACB. Also, $ca = bd$, as these two lines are opposite sides of the parallelogram $cabd$. The components t_1 and w_1 are easily found by solving the right triangle cbd, as follows:

$$t_1 = cd = cb \sin x = w \sin x \qquad (1)$$

$$w_1 = db = cb \cos x = w \cos x \qquad (2)$$

The force t_1 is the resistance due to the inclination of the surface BC, and is independent of the friction. The force w_1, being the normal pressure on the plane, causes a frictional

resistance t_2 equal to the coefficient of friction c multiplied by w_1; that is,

$$t_2 = c\,w_1 = c\,w \cos x \qquad (3)$$

If T is the total tractive force necessary to just pull the wheel up the plane, then,

$$T = t_1 + t_2 = w(\sin x + c \cos x)^* \qquad (4)$$

An expression for the force necessary to prevent the wheel from rolling down the plane is obtained as follows: The direct force pulling the wheel down is t_1; but in this case the frictional resistance t_2 opposes the downward motion; the resultant force T_1 acting down the plane (which is the one that must be applied in an opposite direction to keep the wheel from moving downwards) is, therefore,

$$T_1 = t_1 - t_2 = w(\sin x - c \cos x) \qquad (5)$$

Putting the total rise $A\,B = p$, the inclined length $B\,C = l_i$, and the horizontal length $A\,C = l_h$, the values of t_1, w_1, and t_2 become:

$$t_1 = \frac{w\,p}{l_i} = \frac{w\,p}{\sqrt{p^2 + l_h^2}} \qquad (6)$$

$$w_1 = \frac{w\,l_h}{l_i} = \frac{w\,l_h}{\sqrt{p^2 + l_h^2}} = t_1 \times \frac{l_h}{p} \qquad (7)$$

$$t_2 = \frac{c\,w\,l_h}{l_i} = \frac{c\,w\,l_h}{\sqrt{p^2 + l_h^2}} = c\,t_1 \times \frac{l_h}{p} \qquad (8)$$

from which corresponding values can be written for T and T_1.

17. Approximate Formulas.—Where the inclination is small, l_i is nearly equal to l_h, and, therefore, approximately, $t_1 = \frac{w\,p}{l_h} = w \times \frac{p}{l_h}$; $w_1 = w$; $t_2 = c\,w$ (compare formula of Art. **10**). The quantity $\frac{p}{l_h}$ represents the rate of rise, or **grade**, per unit of (horizontal) length. The rate per

---

*The force T is really only sufficient to balance the resistances; in order that there may be motion, the tractive force must exceed T. But, as any excess of the tractive force over T, no matter how small, will produce motion, it is usually said that T is the force necessary to pull the load up the plane.

100, or per cent., is evidently $100 \times \frac{p}{l_h}$. Denoting the rate per unit by r_1, and the rate per cent. by r_{100}, there results:

$$r_1 = \frac{p}{l_h} \qquad (1)$$

$$r_{100} = 100\, r_1 = \frac{100\, p}{l_h} \qquad (2)$$

$$\frac{p}{l_h} = r_1 = \frac{r_{100}}{100} \qquad (3)$$

Therefore,

$$t_1 = w \frac{p}{l_h} = w\, r_1 = w \frac{r_{100}}{100} \qquad (4)$$

Also,

$$T = t_1 + t_2 = w\left(\frac{p}{l_h} + c\right) = w\left(\frac{r_{100}}{100} + c\right) \qquad (5)$$

If $r_{100} = 1$, and $w = 2{,}000$ pounds, or 1 ton, formula 4 gives $t_1 = 2{,}000 \div 100 = 20$ pounds. That is, the grade resistance on a grade of 1 per cent. is 20 pounds for each ton of load hauled. This is a useful value, which should be memorized.

18. Collision.—Collision is caused by obstacles, such as stones lying on or protruding through the surface, contact with which produces a sudden checking of the forward movement, and requires the load to be lifted over them. The force required to lift the load is measured by the horizontal force that, applied at the axle, is sufficient to raise the load on the wheel to the height of the obstacle. In Fig. 3, the tractive force t_0 and the load w are both applied on the axle a. From the theory of moments, it is known that, in order that the tractive force t_0 may be sufficient to balance, on the obstacle o, the wheel supporting the weight w, the moment of the force t_0 acting with the lever arm y must be

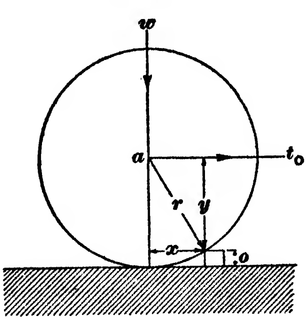


FIG. 3

equal to the moment of the force w acting with the lever arm x; or, algebraically, $t_o y = w x$. Therefore,

$$t_o = \frac{w x}{y}$$

If the radius of the wheel is denoted by r, and the height of the obstacle by o, we have $y = r - o$, and $x = \sqrt{(2r - o)o}$ (see *Geometry*, Part 2); therefore,

$$t_o = \frac{w\sqrt{(2r - o)o}}{r - o}$$

The value t_o, as given by this formula, measures the resistance of the obstacle, and any tractive force greater than t_o will pull the wheel over the obstacle. For small obstacles, this resistance may be considered to be inversely proportional to the square root of the diameter of the wheel. It should be noted, however, that the resistance of small obstacles and inequalities in the roadway surface is due largely to the shock that they produce, and is greater at high than at low speeds.

EXAMPLE 1.—What is the total tractive force required to haul a load of 5,000 pounds on an ordinary macadam roadway having an ascending grade of 4 per cent.?

SOLUTION.—As obtained from Table I, the value of c for ordinary macadam roadways is $\frac{1}{25} = .04$. By formula **5**, Art. **17**, $T = 5{,}000\left(\frac{4}{100} + .04\right) = 400$ lb. Ans.

EXAMPLE 2.—What is the tractive force required to draw a wheel 5 feet in diameter, supporting a load of 400 pounds, over an obstacle 6 inches (= .5 foot) in height resting on a level roadway surface?

SOLUTION.—The radius of the wheel is one-half the diameter, or 2.5 ft. By the formula of Art. **18**, the tractive force t_o is

$$\frac{400 \times \sqrt{(5 - .5) \times .5}}{2.5 - .5} = 300 \text{ lb. Ans.}$$

EXAMPLES FOR PRACTICE

1. What is the total tractive force required to haul a load of 6,400 pounds on a roadway paved with asphalt, and having an ascending grade of 2 per cent.? Ans. 192 lb.

2. What is the total tractive force required to haul a load of 3 gross tons on a roadway paved with good granite blocks, and having an ascending grade of 5 per cent.? Ans. 504 lb.

3. What is the total tractive force required to haul a load of 4,800 pounds on a hard-rolled gravel roadway having a grade of 3 per cent.? Ans. 304 lb.

4. What is the total tractive force required to haul a load of 2 gross tons on an ordinary earth roadway having a grade of 10 per cent.? Ans. 855 lb.

5. What is the tractive force required to draw a wheel 4 feet in diameter, supporting a load of 200 pounds, over an obstacle .4 foot in height, resting on a level roadway surface? Ans. 150 lb.

TRACTIVE POWER OF HORSES

19. The load that a horse can pull on a given road surface is dependent on the weight of the animal, the quality of the foothold afforded by the road surface, the speed, and the duration of the effort. Owing to the difference in weight, strength, and training, the work that can be performed by different animals varies greatly, and it is possible to make only a roughly approximate statement with regard to the average amount of work a horse can do.

20. Average Work of a Horse.—It is considered that a good average horse, weighing 1,200 pounds and traveling at a speed of 2.5 miles per hour, or 220 feet per minute, can exert on a smooth level road a pull or tractive force of 100 pounds, which is equivalent to $100 \times 220 = 22,000$ foot-pounds of work per minute. This represents the work of a rather superior animal, however, and it will probably be more correct to assume that the average horse, working regularly 10 hours a day, can exert a tractive force of 90 pounds when traveling on an ordinary level roadway at a speed of 2.5 miles per hour. This is equivalent to $90 \times 220 = 19,800$, or, say, 20,000 foot-pounds of work per minute. This value will here be used. Hence, for moderate speeds, the average tractive force that can be exerted by a horse will be given by the formula

$$t' = \frac{20,000}{s'}$$

in which t' = average tractive force, in pounds;
s' = speed, in feet per minute.

If the tractive force t' is known, the average speed s' at which a certain load can be transported may also be computed by this formula.

As there are 5,280 feet in a mile and 60 minutes in an hour, speed expressed in miles per hour can be reduced to feet per minute by multiplying by 5,280 and dividing by 60, or by multiplying by the fraction $5,280 \div 60 = 88$.

21. Maximum Work and Power of a Horse.—The work done by a horse is greatest when he moves at a speed of about one-eighth the greatest speed with which he can move when drawing no load; this will be called the **speed of greatest work.** The force exerted at this speed is about .45 of the utmost tractive force that the animal can exert at a dead pull. From this, it may be seen that a horse can exert for a short time a tractive force of about double that which he can exert continuously, so that much heavier loads can be hauled over steep short grades than over the same grades if long. Hereafter, in problems, the maximum tractive force of a horse at a dead pull will be taken at just double the average tractive force as given by the formula in Art. 20.

TABLE II

DECREASE IN TRACTIVE FORCE ON INCLINES WITH DIFFERENT SURFACES

Grade Per Cent.	Earth Per Cent.	Broken Stone Per Cent.	Stone Blocks Per Cent.	Asphalt Per Cent.
1	20	34	28	59
2	34	50	45	75
3	45	60	56	82
4	53	66	64	87
5	59	71	70	90
10	74	84	86	96
15	90	95	93	

EXAMPLE.—What is the tractive force that can be exerted by an ordinary horse at a speed of 4 miles per hour?

SOLUTION.—A speed of 4 mi. per hr. is equivalent to a speed of

$$4 \times 88 = 352 \text{ ft. per min.}$$

Hence, by the formula in Art. **20**, the tractive force that can be exerted by an ordinary horse at such a speed is

$$20{,}000 \div 352 = 57 \text{ lb., nearly. Ans.}$$

22. The decrease in the tractive force of horses on inclines has been frequently investigated; but, owing to the variance in the strength and weight of the horses, and in the character of the foothold and the vehicles, the results vary widely. An average of the results for different road surfaces and grades from 1 to 15 per cent. is given in Table II.

23. Increasing the number of horses to move a load does not increase the tractive force proportionately. The tractive forces will be about as follows:

$$\begin{aligned} 1 \text{ horse } &= 1 \\ 2 \text{ horses } &= .95 \times 2 = 1.90 \\ 3 \text{ horses } &= .85 \times 3 = 2.55 \\ 4 \text{ horses } &= .80 \times 4 = 3.20 \end{aligned}$$

EXAMPLES FOR PRACTICE

1. At what average speed can two horses haul the load of example 1, Art. **18**? Ans. 197.9 ft. per min.

2. What will be the average speed at which two horses can haul the load of example 2, Art. **18**? Ans. 75.4 ft. per min.

3. How many horses will be required to haul, at a speed of 200 feet per minute, a load of 8,000 pounds on a roadway paved with good granite block and having a grade of 2.5 per cent.? Ans. 4 horses

4. How many horses will be required to haul a load of 8,000 pounds at a speed of 200 feet per minute on a roadway paved with asphalt and having a grade of 1.5 per cent.? Ans. 2 horses

GRADIENTS

24. Angle of Repose.—In descending a grade, the component t_1, Fig. 2, becomes an accelerating force, and it may be necessary to apply a holding-back force T_1 (formula **5**, Art. **16**), in order to keep the vehicle from "running away." It is evident, from formula **5**, Art. **16**, that this will be the case whenever t_1 is greater than t_2; that is, when the

component of the weight along the plane is greater than the resistance due to friction. If t_2 is greater than t_1, the force T_1 will be negative, which means that the vehicle will have to be *pulled* down the incline, no holding-back, or brake, force being necessary. It may happen that the resistance of friction is just enough to keep the wheels from rolling down, in which case $t_1 = t_2$; and, therefore, from formulas **1** and **3**, Art. **16**,

$$\sin x = c \cos x$$

In this case, the angle x, Fig. 2, is called the **angle of repose**; it is the angle just beyond which the resistance of friction is no longer sufficient to keep the wheel from rolling. This angle, of course, varies with the nature both of the surface of the incline and of the rolling body.

25. A general expression for the angle of repose may be found from the formula in the last article; for, if the angle of repose is denoted by x_0, that formula gives

$$\frac{\sin x_0}{\cos x_0} = c$$

that is,

$$\tan x_0 = c \qquad (1)$$

Therefore, the angle of repose is the angle whose tangent is equal to the coefficient of friction. Since $\tan x_0 = \frac{p}{l_h} = r_1$, Fig. 2 (here it is assumed that x has the value x_0), and $r_{100} = 100\, r_1$, it also follows that the per cent. of grade giving the angle of repose is

$$r_{100} = 100 \tan x_0 = 100c \qquad (2)$$

EXAMPLE.—What is the rate per cent. of grade giving the angle of repose for an ordinary Belgian-block pavement?

SOLUTION.—From Table I, the value of c for an ordinary Belgian-block pavement is $\frac{1}{40} = .025$. By substituting this value of c in formula **2**, $r_{100} = 100 \times .025 = 2.5$ per cent. Ans.

EXAMPLES FOR PRACTICE

1. What is the rate per cent. of grade giving the angle of repose for a roadway paved with ordinary granite block? Ans. 4 per cent.

2. What is the rate per cent. of grade giving the angle of repose for an asphalt pavement? Ans. 1 per cent.

26. General Considerations Relating to Grades. The steepest grade on a route is commonly spoken of as the **maximum grade**; and the flattest grade—that is, the grade approaching most nearly to a level grade—is commonly called the **minimum grade.** These terms are also applied, respectively, to those grades that have been decided on as the steepest and flattest grades permissible on the road. The maximum and minimum grades will generally be the same as the maximum and minimum permissible grades. The grade adopted as the maximum permissible grade is sometimes called the **ruling grade.** With reference to the maximum and minimum rates of grade, the terms **maximum gradient** and **minimum gradient** are also used.

27. The easiest grades should be used on those portions of the road where the travel is greatest, and the steepest grades where the travel is least. In the vicinity of towns, the grades should generally be easier than at more distant points, because the traffic near a town will usually be greater in amount and heavier in character than at other points.

In order that efficient drainage may be provided for the roadway, the minimum grade should generally not be flatter than 1 per cent., and should never be materially flatter than one-half of 1 per cent., except on first-class pavements.

28. Maximum Grade.—The maximum grade for a given road must be adapted to the class of traffic that will use it, the character of the road surface, and the cost of construction; therefore, no fixed maximum can be adopted for all situations. In general, however, the maximum grade should not be steeper than 9 per cent. for earth roads, 6½ per cent. for gravel roads, and 3 per cent. for macadam roads, in any case where it is possible to keep within those limits; and, preferably, should never be steeper than about 3 to 5 per cent. for any kind of road. In fixing the maximum grade for a given road, the essential conditions are that the greatest resistance to be overcome in ascending shall not exceed the greatest tractive force that a horse is capable of exerting and that the velocity attained in descending shall not be

dangerous. To prevent a dangerous velocity in descending, the inclination should not exceed twice the angle of repose.

The limiting effect of a grade on the tractive force is due principally to the rate of the grade; the length affects the horse to some degree, on account of the fatigue caused by long-continued exertion. The foothold afforded by the surface is a very important factor: the smoother the surface, the less must be the rate of grade. Earth affords a better foothold than macadam; hence, steeper grades can be used with the former than with the latter.

29. Most Advantageous Grade.—It is frequently necessary to determine whether the grade selected as the maximum is the most advantageous for the traffic that will be done on the road. This is a comparatively complicated problem, the detailed solution of which is beyond the scope of this work. Briefly outlined, the solution is as follows: The approximate annual amount of the traffic, the annual cost of hauling it, the cost of constructing the road and the annual interest on the cost, the annual payments to the sinking fund to extinguish the cost, and the annual cost of maintenance are computed for each of the several grades; the one for which the gross annual cost is the least will be the most advantageous to the community using it. As a result of investigations, it has been deduced that, dependent on the amount of traffic and the cost of construction and maintenance of the road, the most advantageous gradients vary for mountainous country between 5 and 3 per cent.; for hilly country, between 3 and $2\frac{1}{2}$ per cent.; and for gently rolling country, between 1 and $2\frac{1}{2}$ per cent.

30. Total Resistance on a Grade.—The total resistance on a grade is the sum of the resistance due to gravity and the resistance due to friction. In figuring the resistance due to gravity, the weight of the horse should be included.

FORM AND WIDTH OF ROADBED

31. Cross-Section of Road.—To hasten the removal of the rain water from the surface and prevent it from soaking into the subsoil, the center of the road is raised above the sides. The amount of rise depends on the character of the surface; earth requires the most, asphalt the least.

As to the amount of rise and the manner in which it should be given, there is much difference of opinion. It should, however, be borne in mind that excessive rise or convexity renders traffic difficult, and is very dangerous on roads that are frozen slippery; it causes the traffic to follow the center of the wheelway, that being the only part where the vehicle can run upright, and consequently the wear of the road is increased.

32. On hillside and mountain roads, the surface is sometimes formed of a single slope inclining inwards, in which case the water from the road and slopes of the mountains is conducted by pipes and culverts laid under and across the road. The inner half of such a road is usually subjected to more traffic than the outer half; it is thus worn hollow, retains water, and consequently is difficult to keep in repair.

33. On roads used by motor vehicles, the cross-slope on curves must be a single slope pitching inwards, and the outer edge should be raised from 4 to 8 inches above the center, the amount depending on the sharpness of the curve.

34. Since the flow of the surface water follows the line of greatest descent, which is composed of the longitudinal and lateral inclinations of the road, the cross-slope should be regulated by the gradient; the steeper the grade, the less the cross-slope. However, enough cross-slope must be given to prevent the rain water from running off in the direction of the road, otherwise it will cause washouts and destroy the roadbed.

35. Form of Cross-Section.—Different forms have been proposed and used for the cross-section of the road, among them being straight lines inclining from the center

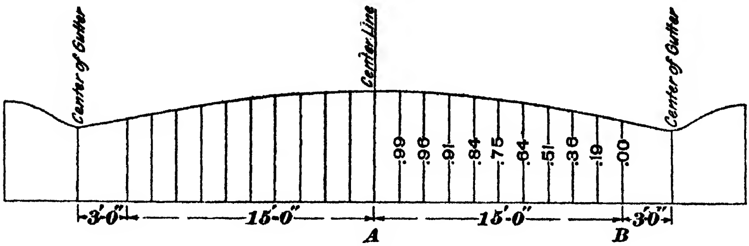


FIG. 4

toward the sides, circular arcs, elliptic arcs, and parabolic curves. A parabolic arc, as shown in Fig. 4, is one of the best forms. Its construction is as follows:

Divide the width *AB* between the edge of the gutter and the center of the wheelway into ten equal parts, and at the points of division raise perpendiculars, the lengths of which are determined by multiplying the rise at the center by the number given on each perpendicular in the figure. The rise at the center should be as follows: for earth roads, $\frac{1}{40}$ the width; for gravel roads, $\frac{1}{50}$ the width; and for broken-stone roads, $\frac{1}{60}$ the width.

EXAMPLE.—To find the ordinates for an earth road 30 feet wide.

SOLUTION.—The center height must be $\frac{30}{40}$ = .75 ft. The distance between the center of the road and the edge of the gutter is 15 ft.; the points of division are, therefore, 1.5 ft. apart. The ordinates are as follows (see Fig. 4):

At the center,		.75 ft.
At $1\frac{1}{2}$ ft. from the center,	$.75 \times .99 =$	.74 ft.
At 3 ft. from the center,	$.75 \times .96 =$	.72 ft.
At $4\frac{1}{2}$ ft. from the center,	$.75 \times .91 =$	.68 ft.
At 6 ft. from the center,	$.75 \times .84 =$	.63 ft.
At $7\frac{1}{2}$ ft. from the center,	$.75 \times .75 =$	.56 ft.
At 9 ft. from the center,	$.75 \times .64 =$	.48 ft.
At $10\frac{1}{2}$ ft. from the center,	$.75 \times .51 =$	.38 ft.
At 12 ft. from the center,	$.75 \times .36 =$	.27 ft.
At $13\frac{1}{2}$ ft. from the center,	$.75 \times .19 =$	.14 ft.
At 15 ft. from the center,		.00 ft.

36. Width of Roadway.—The width of the wheelway on country roads should be just sufficient to conveniently accommodate the traffic upon it. Any unnecessary width causes increased cost in construction; while very narrow roads are disadvantageous because they wear badly, since on them the traffic is confined to a single track, thus quickly forming ruts. Experience shows that, if a wide and a narrow road are both subjected to the same amount of traffic, the cost of maintenance is less for the wide than for the narrow road.

37. The minimum width of the wheelway, if intended to accommodate two lines of travel, is fixed by the width required to allow two vehicles to pass each other safely. This width is 18 feet. If the road is intended for a single line of travel, 8 feet is sufficient, but suitable turnouts must be provided at frequent intervals. The wheelway on an earth road should be wider than on an improved road, so that the traffic can spread out and avoid cutting up the road during rainy weather. As the road approaches a town, the width of the wheelway should be increased to accommodate the larger amount of traffic.

Foot-paths, when used, should have a width of about 7 feet, and between them and the wheelway the strips reserved for future increase in width of the wheelway may be laid down in grass.

38. Width of Right of Way.—The entire area of a road included between fence lines is commonly known as the **right of way**; it is so called because it is the strip of land over which a right of ownership must be obtained, by purchase or otherwise, from the owners of the properties over which the road passes. The best width for the right of way of a road is a matter that must be determined by judgment and according to the requirements of each particular case. When possible, it should be sufficient for future widening of the road as the traffic increases. The widths of country roads vary greatly. A width of 4 rods, or 66 feet, is common for important roads in some localities. In other places, very

narrow roads are not uncommon, some being little more than narrow lanes, probably not more than a rod in width. Roads 3 rods, or $49\frac{1}{2}$ feet, in width are very common.

A width of 66 feet was probably first adopted largely for convenience of measurement and computation, it being the length of a surveyors' chain. It has proved to be a good practical width, however, and is often used for both country roads and city streets. It is wide enough to accommodate all possible requirements, and is about as narrow as is generally desirable for northern climates, as the snow drifts caused by the fence lines will often extend across and block the roadway in narrower roads. Rights of way narrower than 66 feet are, however, very common.

39. Curves.—The straight parts of the roads must be joined by curves, the least permissible radius of which depends on the length of the teams using the road. As a rule, the greatest possible radius should be used. No curve should have a radius of less than 50 feet. The curves may be either circular or parabolic. A parabolic curve is often preferred, on account of the ease with which it can be laid out.

LOCATION OF ROADS

RECONNAISSANCE AND PRELIMINARY SURVEY

40. Reconnaissance.—In order to select the most advantageous route, certain information must first be obtained regarding the physical features of the country to be traversed. The operation by which this information is procured is called the **reconnaissance**, or **exploration**. This is effected by either walking or riding over the proposed route. With a good contour map, the work is much facilitated, because the approximate position of the line may be determined with reasonable certainty before going into the field, and notes can be made on the map of the different lines from which a selection may afterwards be made.

41. The information to be sought in the exploration includes: (1) the general features of the country—that is, the general positions of rivers, streams, roads, trails, railroads, villages, valleys, summits of hills, gaps or passes, with the general angles of inclinations and altitudes; (2) the geological features, the character and inclination of the strata, and the sources from which materials may be obtained for the construction of the proposed road; and (3) the probable requirements of the districts passed through.

42. The instruments employed in the reconnaissance are the pocket compass for ascertaining directions, and the aneroid barometer and hand level for obtaining approximate elevations. Distances are estimated by the eye or with the aid of a pedometer.

If the character of the country is such that an ordinary reconnaissance will fail to give the desired information, an exploration may be made by means of transit and stadia.

43. In reconnoitering a tract of country, the first feature to attract the observer's attention is the apparently endless combination of irregular and undulating forms composing the surface. On close examination, it will be perceived that two classes of configuration obtain, even in the most irregular country; namely, the hills and the valleys.

An acquaintance with the system controlling the configuration will very much lessen labor and time. It will be noticed that the country is intersected in various directions by main valleys, through which flow the main watercourses or rivers, which increase in size as they approach the point of their discharge. Toward the main rivers, smaller rivers approach on both sides, running right and left through the country, and into these, again, enter still smaller streams and brooks. The streams separate the hills into branches or spurs, which have approximately the same course as the waterway, and the ground rises in every direction from the watercourses, forming slopes, the intersections or apexes of which form ridges of greater or less height; these ridges slope up to the tableland into which their summits merge.

The watercourses thus mark not only the lowest lines, but also the lines of greatest longitudinal slope. The position of the tributaries to the larger streams indicates generally the points of greatest depression in the summits of the ridges, hence the points at which lateral communication across the tableland separating contiguous valleys can be most easily made. If two or more streams diverge from any point, that point will be the highest part of the section; while, if several streams converge to a common point, that point will be the lowest.

44. The amount of work that it is necessary to expend on a reconnaissance will depend on the difficulties attending each particular case, but neither time nor labor should be improperly economized, as a careful reconnaissance will save much future expense in the location, construction, and maintenance of the road.

45. Preliminary Survey.—On the completion of the reconnaissance, preliminary surveys with transit and level are made of the routes deemed most advantageous. In these surveys, particular attention is given to the **ruling points,** or the points through which the road must pass, such as the lowest gap in a range of hills and the most feasible crossings of rivers. The topography is noted for a convenient distance to the right and left of the line; notes are also made of the character of the material to be excavated or available for embankments, the position of quarries and gravel pits, and the modes of access thereto. The results of the preliminary survey are plotted in the form of a contour map, from a study of which the approximate final location of the road can be determined. Such a map is shown in Fig. 7. How this map is utilized for the selection of the best route will be explained further on.

SELECTION OF ROUTE

46. With the aid of the contour map made from the data obtained in the preliminary surveys, as just described, the final route may be approximately laid down on the map. In doing this, certain principles should be observed as far as practicable. The terminals and ruling points should be connected by the shortest and most direct route consistent with economy and easy grades. Directness and distance may have to be sacrificed in order to secure easy grades. It is generally better to curve around a very steep hill than to go straight over it. A judiciously located route around the hill will not be materially longer than a direct route over the hill, for the reason that both lines are curved: the line over the hill is curved in a vertical plane; while the circuitous line around the hill is curved in a horizontal plane. For example, if a circular hill has slopes of 50° 26′ on both sides, the distance around it on a level is no longer than the line over it, and by going around it, the waste of tractive power required to raise the load over it is avoided. The total length of a circuitous route will often exceed that of a direct line, but, if the grades of the former are less than those of the latter, the loss through increase of distance may be compensated by the gain in speed and the heavier loads permitted by the easier grades.

Marshy or wet ground should be avoided, because of the difficulty and cost of securing a good foundation and drainage.

47. Deep valleys should be crossed at as high an elevation as practicable. A narrow part should be selected, and, if a bridge is required, the crossing should be at right angles. All obstacles where structures are necessary should be crossed as nearly as possible at right angles. The cost of skew structures increases nearly as the square of the secant of the angle.

When the line runs along the side of a valley, the obstacles that it has to cross are chiefly the small branch valleys

running into the main valley, and the promontories or ridges that separate and form the small valleys. Under these circumstances, the greatest economy will generally be attained by curving around the promontories in a serpentine course. In some cases, it may be cheaper to make a straight crossing and avoid the detour; this can only be determined for each particular case by comparing the cost of construction with the cost of operation and maintenance.

When a river has to be crossed, the point of crossing is a ruling point, and the line of the road must be made subordinate to it. Careful study should be given to selecting the best site for the bridge. The conditions that govern the selection of the site are: (1) a good foundation for the abutments and piers; and (2) stability of the banks, to insure the permanent concentration of the waters in the same channel. The approaches to the bridge should be free from sharp curves and steep inclines, and the axis of the bridge should, if possible, be placed at right angles to the direction of the current.

48. Roads placed in the lowest parts of valleys are subject to flooding, while those on the side of a hill, where the strata are inclined toward the valley, or the slopes are composed of loose material or permeable rock with seams of clay, are liable to slips and washouts caused by the action of frost or heavy rainfalls.

In placing the line on a hillside, the direction of the inclination of the strata should be observed, and the line located so that it will be opposed to that inclination. In Fig. 5, a

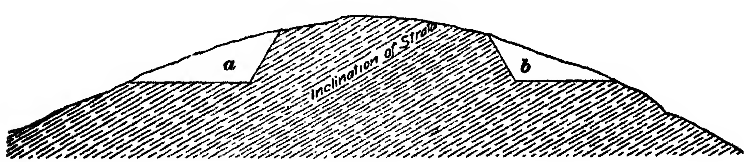


Fig. 5

road located at *a* will be exposed to the accidents of landslides, which will be a source of continual trouble and expense; while the road located at *b* will be free from

danger. In very deep excavations having long slopes, the slope is cut in benches, as shown at *a*, Fig. 6, in order to prevent the water from acquiring a high velocity. The benches may be placed about 5 feet apart, and have a width of 1 to 5 feet. The surface of the benches should be sloped

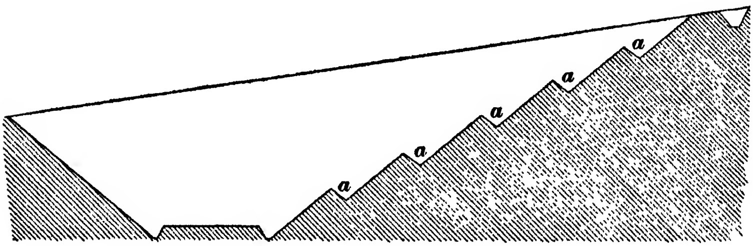


FIG. 6

inwards to intercept material that may slip, and to check the velocity of the rain water flowing down the slope.

This class of work involves increased expense in construction, which should be taken into consideration when weighing the advantages and disadvantages of different routes.

49. Deep cuttings should be avoided, unless the gain is so clear and substantial as to justify the greater cost of construction and maintenance. Cuttings at high elevations are exceedingly objectionable, on account both of the difficulty in keeping the slopes in repair and of the danger of snow drifts. In a choice between a shallow cut and a low embankment, the embankment is to be preferred, for the reasons that the drainage can be made more effective and that there will be less trouble in keeping the road open in time of snow.

50. In locations subject to heavy snowfalls, the road should, if possible, be located on the slopes facing south and east, as in these directions the power of the sun to melt snow is greatest.

51. For the purpose of avoiding accidents, railroads should be crossed either overgrade or undergrade. This rule has not been observed in the past, except on a few

heavy-traffic roads in the vicinity of cities; but it is a rule that should be followed wherever possible, for grade crossings mean danger to every user of the highway.

52. If the course of the road is transverse to the direction of streams, it will have steep ascents and descents, and be exceedingly expensive to construct and maintain.

Roads that run along the immediate bank of a river must of necessity intersect all the tributaries confluent on that bank, thereby demanding a corresponding number of bridges, which are expensive to build and maintain.

53. Particular efforts should be made: (1) to cross ridges through the lowest pass; (2) to establish the grade line with reference to the natural surface so that it will lie above the highest water level of the side ditches; (3) to establish the grade line so that the cuts and fills will be equalized as nearly as possible; (4) to adjust the route so that it will follow the division line of properties as nearly as possible, provided that such adjustment does not materially affect the grade and cost of construction and maintenance.

COMPARISON OF ROUTES

54. Conditions to be Compared.—Where it has been found necessary to run more than one line in order to select the best route, the profiles of the different lines will afford a fair basis of comparison. The principal conditions to be considered in comparing the routes are as follows:

1. *Convenience to Traffic.*—The road should, as far as possible, be located in such a position that it will satisfactorily accommodate those who are to travel upon it. The route that will best accomplish this, and, at the same time, afford equal advantages in regard to the other essential conditions, will be the best route.

2. *Short and Direct Route.*—The matter of distance should receive consideration. All other conditions being equal, the shortest route will be the most quickly traveled over, and, therefore, will be the best.

3. *Easy Grades.*—The route having the easiest grades will allow the heaviest loads to be hauled on it and permit the highest rate of speed; consequently, if all other conditions are equal, it will be the best route.

4. *Small Rise and Fall.*—The route having the smallest total amount of rise and fall will offer the least total resistance to the traffic, irrespective of the steepness of its grades. Hence, with all other conditions equal, such a route will be the best.

5. *Thorough Drainage.*—The route selected should have such position and such grades as will afford the opportunity for thorough drainage of the roadway.

6. *Suitable Material for Roadway.*—When there is any difference in regard to the character of the soil along the different routes, the route having the best material should be selected, provided that all other conditions are fulfilled to an equal extent.

7. *Small Cost.*—With all the foregoing conditions equally fulfilled, the route that can be constructed and maintained at the least cost will be the best. The matter of cost is a very important consideration, and in many cases it is the governing condition.

From the conditions mentioned, it will be noticed that the considerations involved in the comparison of the routes are of two kinds; namely, those relating to the efficient accommodation of the traffic, which is the result produced, and those relating to the cost of producing this result. The first six conditions named are of the former class; the last condition is of the latter class.

55. Means and Method of Comparison.—A comparison of all except the first of the conditions noted in the preceding article will be given by the profiles of the routes. The length, grades, rise and fall, character of the soil, and, to some extent, the opportunity for thorough drainage will be shown for each route by an inspection of its profile, from which the approximate cost of construction may also be easily estimated.

In comparing the gradients, the rates of grade should be compared with special reference to the rates of maximum grade on the different routes, as this condition will greatly affect the magnitudes of the loads that can be hauled over the roads.

In the comparison of the lengths of the routes, the total *ineffective rise* and the *excessive fall* should be included. By **ineffective rise** is meant that rise and fall in the grade that is not due to the difference of elevation between the two ends of the route; it is the total number of feet actual rise in the grade line encountered in passing from the higher end of the route to the lower end. By **excessive fall** is meant that fall in the grade that is in excess of certain rates of grade encountered in passing in the same direction. Should the grade line on any portion of the route, in passing from the higher to the lower end, fall more than 9 per cent., 6.5 per cent., or 3 per cent. for earth, gravel, or macadam roads, respectively, each foot of fall in excess of such rates will be considered as excessive fall. These are about the average rates of grade, giving, respectively, the angle of repose for the three kinds of roadways named. On descending grades steeper than these, a holding-back force must necessarily be applied to the loads. Ineffective rise and excessive fall are both counted in a direction passing from the higher to the lower end of the line.

56. The length of the route, taken in connection with the ineffective rise and excessive fall, is called its **resisting length.** The resisting lengths of different routes may be compared by referring them to the work required to move a given load along them. If c is the coefficient of friction, the work U performed in hauling a weight W along a horizontal distance h is given by the formula

$$U = W c h$$

If, however, in the distance h there occurs a rise (or excessive fall) r, the work U' necessary to haul the weight along the inclined path is

$$U' = W c h + W r$$

In order to reduce this to an equivalent level grade, U' must be given a form similar to that of U. Putting $r = c\,h'$, where $h' = \frac{r}{c}$, the value of U' becomes

$$U' = Wch + Wch' = Wc(h + h')$$

which shows that the inclined path is equivalent to the corresponding horizontal path increased by the quantity h', or $\frac{r}{c}$. In general, if l is the length of a route, and l_0 is the equivalent length of a route having, with respect to the former, a sum of excessive falls and ineffective rises equal to r, we have

$$l_0 = l + kr$$

where $k = \frac{1}{c}$, and may have the following* average rough values: for earth roads, $k = 12$; for gravel roads, $k = 20$; for macadam roads, $k = 33$. By comparing the resisting lengths obtained by applying this formula to the grade lines of the different routes, a reasonably accurate comparison may be made between the routes in regard to what may be considered the comparative resistances that they oppose to traffic by reason of actual length, ineffective rise, and excessive fall.

57. Some comparison of the character of the soils along the different routes, with reference to their adaptability to the purposes of road building, may be obtained from the notes given on the profile. For each route, the opportunity for thorough drainage can be largely judged from the profile. The amount of grading, as estimated for each line from its profile, taken in connection with the amount of bridging and number of culverts required, as shown on the profile, will serve as a basis for estimating the relative cost of the different lines.

58. A comparison of the first condition (convenience to traffic) can be made only by examining the routes on the

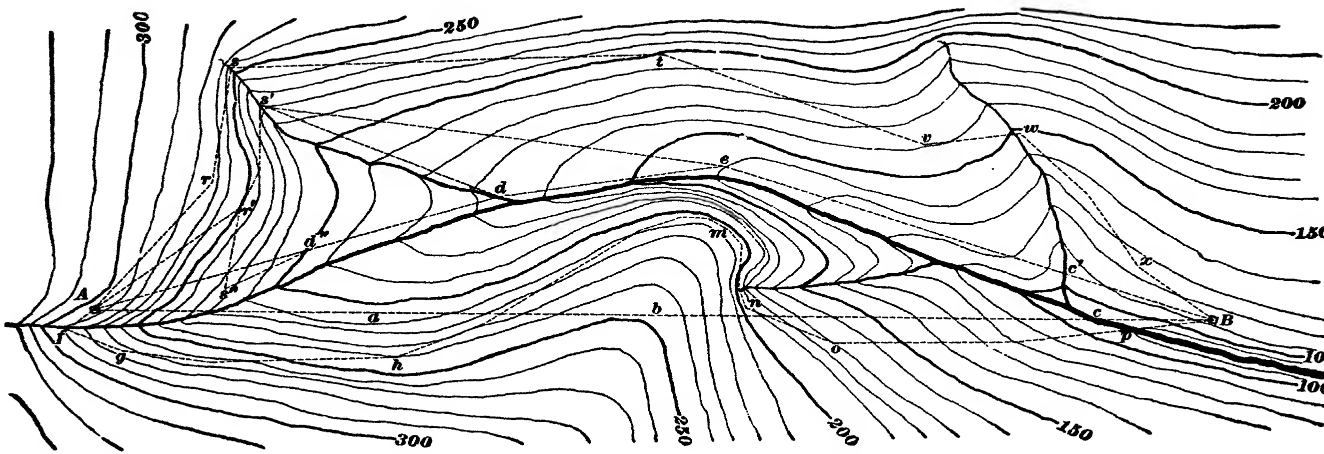
*These average values may be used for ordinary roads and rough estimates. The actual values will generally vary from about 7 to 22 for earth roads, 15 to 30 for gravel roads, and 30 to 40 for macadam roads, according to the condition of the roadway surface (see Art. **10**).

ground or on a very complete map. The road should, as far as practicable, be so located as to be the most convenient for the greatest portion of its traffic. The position of a road that will best accommodate its traffic will generally be that in which, all other conditions being equal, the sum of the distances through which each ton of freight is moved and each passenger travels will be a minimum; in other words, it will be that position which will require the mass of the traffic to be moved the least distance in reaching its destination. Some consideration should also be given to the question of whether a road will be pleasant for those who are to travel on it. In the case of pleasure drives, this should be an important condition.

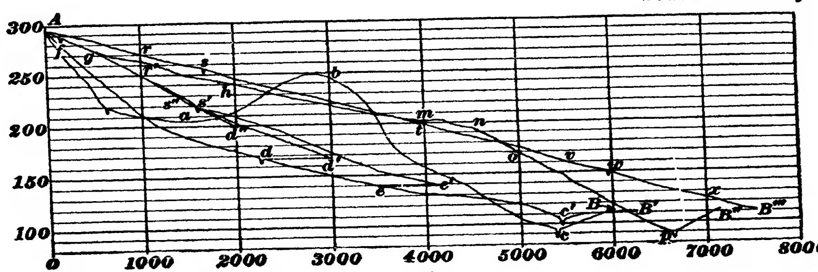
EXAMPLE OF ROAD LOCATION

59. As an illustration of road location, let it be assumed that it is desired to locate and construct a highway between the points *A* and *B*, Fig. 7 (*a*), which are 6,000 feet, or slightly more than $1\frac{1}{8}$ miles, apart, measured in a direct line. The topographical features of the country are shown in the figure, the relative elevations being shown by contour lines. It will be assumed that the road is to be constructed to sustain a very heavy traffic between the points *A* and *B*, and that it is not essential for it to pass through any intermediate points, though rather desirable that it should pass through or near the points *d* and *e* in the valley, provided that such location will not be disadvantageous in other respects. As the road is one of considerable importance, several routes are surveyed, in order to determine the best route. The profiles of the different routes are shown below the map in Fig. 7 (*b*). Only the surface lines are shown in these profiles. In order to avoid confusion in comparing the different profiles, the grade lines have been omitted; they may be considered to have approximately the same positions as the surface lines and to be somewhat more uniform.

60. The direct route *A a b c B* is the shortest as regards horizontal distance, being just 6,000 feet long, horizontally.



Scale 1" = 1000 ft.



(b)

Fig. 7

But the profile shows that, in passing from the higher terminus A to the lower terminus B, by this route, a rise of about 43 feet is encountered between a and b, and another rise of about 19 feet occurs between c and B, making a total ineffective rise on this route of $43 + 19 = 62$ feet. Between the end A of the line and the first crossing of the stream, which is a distance of 625 feet, the fall is about 75 feet, or at the rate of

$$\frac{75 \times 100}{625} = 12 \text{ per cent.}$$

Assuming that the road is to be an ordinary earth road, that part of the fall in excess of 9 per cent. should be treated as a like amount of rise (see Art. **55**). A fall of 9 per cent. for a distance of 625 feet makes a total fall of $9 \times 6.25 = 56.25$ feet, leaving an excess of $75 - 56.25 = 18.75$ feet. Also, in the 400 feet of horizontal distance, situated between points distant 350 and 750 feet, respectively, to the right of b, the fall is about 50 feet, or at the rate of

$$\frac{50 \times 100}{400} = 12.5 \text{ per cent.}$$

which is an excess of $12.5 - 9 = 3.5$ per cent., or a total excess of $4 \times 3.5 = 14$ feet. By applying the formula in Art. **56**, the length of route l_o to be assumed in making the comparison is

$$6{,}000 + 12 \times (62 + 18.75 + 14) = 7{,}137 \text{ feet.}$$

This route would also involve very steep grades, the maximum in one direction being not less than 12 per cent., and in the opposite direction about 5 per cent.

61. The route $A\,d\,e\,B$, following the general course of the stream, would usually be the route first tried, especially if the surveys were made from the lower terminus B toward the upper terminus A, as will most commonly be the case. The surface line $A\,d\,e\,B'$ is the profile of this route. It will be seen from this profile that the route is a favorable one, having only the very small amount of ineffective rise that occurs between c' and B. The length of this route is 6,250 feet. In the first 1,000 feet from A, however, this route has a fall

of about 85 feet, requiring a grade of 8.5 per cent., which is steeper than is desirable for the character of the traffic that the road is to sustain.

In the attempt to avoid this steep grade, the lines $A\,r'\,s'\,d$ and $A\,r'\,s'\,e$ are run as alternative lines for a part of this route. The profiles of these lines are shown by the surface lines $A\,r'\,s'\,d'$ and $A\,r'\,s'\,e'$, respectively. The line $A\,r'\,s'\,d$ increases the length of the route by the amount $d\,d'$, or about 700 feet, and the line $A\,r'\,s'\,e$ increases it by the amount $e\,e'$, or about 600 feet. Hence, the total horizontal length of the line $A\,s'\,d\,B$ will be $6{,}250 + 700 = 6{,}950$ feet, and the total horizontal length of the line $A\,s'\,e\,B$ will be $6{,}250 + 600 = 6{,}850$ feet. There is no excessive fall in this line, but between the points c' and B there is about 8 feet of ineffective rise, giving a theoretical increase of $8 \times 12 = 96$ feet in the length of the line. For the purposes of comparison, therefore, the value l_0 for the line $A\,s'\,d\,B$ is $6{,}950 + 96 = 7{,}046$ feet, and for the line $A\,s'\,e\,B$ it is $6{,}850 + 96 = 6{,}946$ feet. For both these lines, the maximum grade, which occurs between r' and s', is 5 per cent.

62. The route $A\,f\,h\,m\,o\,B$ is surveyed at a higher elevation along the opposite side of the valley. This line is a modification of the direct line $A\,b\,c\,B$; it is very crooked, however, and its length, horizontally, is about 7,060 feet. For this route, the surface line $A\,h\,n\,B''$ is the profile. Its maximum grade, which is between n and p, is 5 per cent. Between the point p and the terminus B, there is about 12 feet of ineffective rise, making the value of l_0 for this route equal to

$$7{,}060 + 12 \times 12 = 7{,}204 \text{ feet}$$

63. Route of Easiest Grade.—As the traffic on the road is to be of a very heavy character, making easy grades a very important consideration, still another line is surveyed, for the purpose of ascertaining whether a line having very easy grades can be obtained. This line is located very carefully, with the object of obtaining, if possible, a line having no grade steeper than 2.5 per cent. Such a line is

obtained; it is the line $AstvwB$, having a length of about 7,550 feet. There is no ineffective rise or excessive fall on this line. The surface line $AstwB'''$ is the profile of this line. The greater part of the line approximates a uniform grade of 2.4 per cent., and a maximum grade of 2.5 per cent. can be easily obtained.

64. Tabulated Comparison.—In order to afford a ready comparison between the different lines surveyed, the values that have been determined are assembled below in tabular form. For convenience of reference, the different lines are numbered.

Number of Route	Line	Actual Length l Feet	Resisting Length l_0 Feet	Maximum Grade Per Cent.
1	$AbcB$	6,000	7,137	12.0
2	$AdeB$	6,250	6,250	8.5
3	$As'dB$	6,950	7,046	5.0
4	$As'eB$	6,850	6,946	5.0
5	$AmoB$	7,060	7,204	5.0
6	$AswB$	7,550	7,550	2.5

This tabulation of values, together with the map and profiles of the routes, will allow an intelligent selection of the route to be made. From the values of l_0 and of the maximum grade, it is seen that routes Nos. 2, 4, and 6 are the most favorable ones. Route No. 2, or the direct route through the valley, is a thoroughly practical route, provided that the maximum grade of 8.5 per cent., extending for a distance of 1,000 feet, is not objectionable. This route gives the smallest value of l_0. Route No. 4 is a modification of route No. 2; it reduces the maximum grade to 5 per cent., and increases the length of the line nearly 700 feet. Route No. 6 follows the brow of the hill on the left side of the valley. This is the longest of the routes surveyed, but it obtains the very easy maximum grade of 2.5 per cent., and, as it has no ineffective rise and fall, it gives a value of l_0,

which is the same as the actual length of the line. This is by far the best route for heavy traffic, and for a mixed traffic will generally be the most satisfactory. If it is necessary to pass through the points *d* and *e*, and, at the same time, have no grade steeper than 5 per cent., route No. 3 will fulfil the conditions; but, if there is no reason why the road should pass through the point *d*, route No. 4, which is a little shorter, is preferable.

FINAL LOCATION

65. Running and Marking the Line.—When the final route has been selected, it is necessary to mark it on the ground. This is done by running with the transit and chain, or tape, the determined curves and tangents along the center line of the road, and placing numbered stakes at each 50 or 100 feet on the tangents, and at each 25 feet on the curves. The stakes are numbered consecutively, beginning with zero, as in railroad work. At transit stations, at the intersection of tangents, and at the tangent points of curves, a larger stake, called a **hub**, is placed, and the exact position of the point is fixed by a tack driven in the top of the hub. The location of these hubs is shown by a side stake, on which is marked the number of the station and the plus, if the point falls between stations.

66. Reference Points and Monuments.—The positions of the points of intersection of tangents and of the points of beginning and ending of curves are fixed on the ground by measurements to permanent objects; in the absence of these, four stakes, called **reference stakes**, are driven outside the limits of the ground that will be disturbed during the construction of the road, and the directions and lengths of the lines between them and the point are carefully measured. After the road has been constructed, the point is relocated, and a stone or iron monument is placed either directly at the point or on some convenient offset thereto. The position of the monument is fixed by measured courses and distances to two or more permanent objects. These

marks can be relocated at any time, thus avoiding controversy in after years regarding the position of the road.

67. Levels.—In conjunction with the tracing and staking of the line, levels are taken at each station, and at the crossings of roads, railroads, and watercourses. A sufficient number of cross-levels is taken to determine the extent of any changes in the grade of such roads and in the height and dimensions of culverts and bridges.

The level notes should be worked up each evening for that part of the line run during the day, and the grade line established. In this way, changes for the betterment of the location of the line or the balancing of cuts and fills can be noted, and any unsatisfactory parts relocated the next day.

Bench marks to be used in the subsequent construction should be established at short intervals on permanent points, such as abutments of bridges, neighboring rocks, large trees, sills of houses, etc.

68. Report.—The engineering report on the proposed road should contain all the information that cannot be shown on the map and profile. The report should be accompanied by:

1. A general map, drawn to a scale ranging from $\frac{1}{200000}$ to $\frac{1}{20000}$.

2. A detailed map drawn to a scale ranging from $\frac{1}{600}$ to $\frac{1}{300}$.

The maps should show the courses and distances along the center line, the radius and length of each curve, the topographical features, the property lines and buildings adjacent to the proposed road, and the names of the property owners and the acreage owned by each.

3. A longitudinal section or profile, the horizontal scale of which corresponds to that of the detailed map, the vertical scale being 25 times larger.

4. Cross-sections where needed.

5. The designs for bridges, culverts, etc.

6. The estimate of the cost.

69. Construction Profile.—The construction profile is drawn to convenient horizontal and vertical scales, and

contains: (1) the datum line to which the levels are referred; (2) the stations at which the levels were taken; (3) the elevations of the surface above the datum; (4) the grade line and its elevation at each station; and (5) the depths of the cuttings and the heights of the embankments.

Fig. 8 represents part of a construction profile. The two straight parallel lines represent the grade of the road. The upper line shows the finished road surface; the lower line shows the subgrade. The figures in column A are the elevations of the grade above datum. The figures in column B are the elevations of the ground above datum at every 100

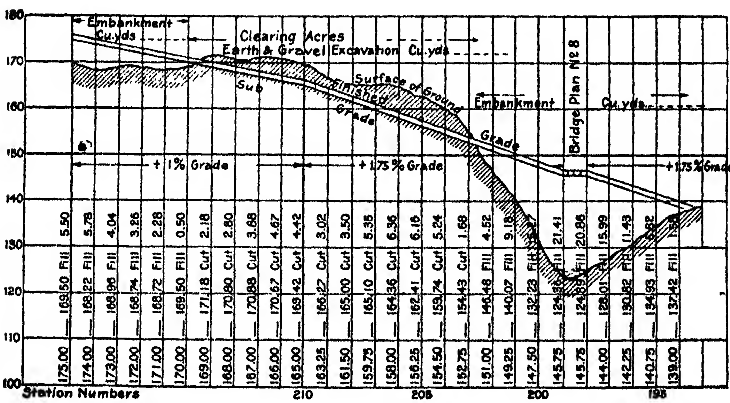


FIG. 8

feet, and wherever else stakes have been set. The figures in column C are the depths of cut and the heights of fill; they are obtained by taking the difference between the elevation of the surface of the ground and the elevation of the subgrade. All the dimensions here shown refer to the subgrade, to which the surface of the ground is to be formed in order to receive the road covering. The points at which the grade line changes inclination should be well defined on the profile. This is usually done by drawing a heavy red vertical line at each point of change.

70. Maps and Records.—When the route of a highway has been satisfactorily and finally located, a map of the line

should be made for the purpose of record, showing accurately all its courses, angles, and distances, the points at which it crosses land boundaries, section lines, streams, railroads, and existing highways, together with the courses and distances to and the description of all witnesses taken at the angles and at the starting and terminal points of the line. The map should also show the positions of the starting and terminal points, as well as convenient points along the line with reference to the nearest corners of the Government land survey, if there are any such corners near the line. The map may also show a profile of the line. Such profile, although not essential, is valuable for purposes of reference regarding grades and drainage.

All information given on the map proper—that is, all information relating to the alinement and position of the line—should be given also in an accurately written description of the surveyed line. The map and description should be filed for a permanent record with the proper township or county officials.

STAKING OUT THE WORK

71. For the purpose of guiding the workmen, the boundaries of the embankments and cuttings, and the locations of culverts, drains, and ditches, must be marked on the ground by stakes. The amount of cut or fill is marked on the center stake on the side opposite to that on which the station number is marked. The points at which the slopes meet the natural surface of the ground are fixed by slope stakes, the positions of which are determined as in railroad work.

72. In marking the amount of fill on the stakes, it is usual to add the amount required to compensate for settlement; if this is not done, the contractor or person in charge of the construction must be advised as to what amount to add to the figures marked on the stakes. The amount of the allowance for the settlement or shrinkage depends on the character of the material and the manner in which it is handled. All materials (rock excepted) increase in bulk when excavated, but, after being deposited in banks, subside,

settle, or shrink until they occupy less space than they did before being excavated. The reason for this shrinking is that soils in their natural position contain a greater or less percentage of voids, caused by the solution of their soluble constituents by percolating water, and by the disrupting effect of alternate freezing and thawing; soils subjected to this action shrink more than soils excavated from below the usual frost line. The soils that shrink the most are the loams, and those that shrink the least are the sands and gravels. The condition of the soil and of the weather at the time the soil is being handled affect the shrinkage to some extent: if the soil is moist or is placed in the bank during wet weather, the shrinkage is greater than when the soil is dry and handled during a dry period. The method of handling, too, affects the shrinkage: material thrown by shovels or dumped from wheelbarrows shrinks more than material put in place by drag scrapers or carts.

The usual allowance for shrinkage is as follows: gravel, 8 per cent.; gravel and sand, 9 per cent.; clay, 10 per cent.; loam and light sandy soils, 12 per cent.; loose vegetable soil, 15 per cent. Rock increases in volume from 40 to 50 per cent. by being broken up, and does not settle again to less than its original bulk.

73. In placing the stakes for culverts or other structures, they must be placed so as to be permanent during the time occupied in the construction, and in such positions that lines can be drawn from one to the other to determine the finished or face lines of the structure. Stakes are also required at the zero points, or the points where an excavation ceases and an embankment begins; at such points there is neither cut nor fill.

74. Curves.—The curves in highways are marked out in the same manner as in railroad work, the only difference being that, as the radii are less, shorter chords are used. The length of the chord is usually 20 feet; on curves having a radius of 50 to 100 feet, it will be better to place the stakes at distances of 10 to 15 feet. Vertical curves are made parabolic (see *Railroad Location*).

EARTHWORK

75. Computing Earthwork.—The amount of excavation and embankment is expressed in cubic yards, and the contractors that perform the work are paid a certain price per cubic yard of material excavated, the price depending on the kind of material. The volume of excavation is computed from the cross-sections obtained at the time of staking out the work, by using either the prismoidal formula or the method of average end areas, as explained in *Earthwork.*

76. Equalizing the Earthwork.—In establishing the grade of a road, attention should be given to the equalizing, as nearly as possible, of the cuttings and embankments, so that the material excavated will be just sufficient to form the embankment. When this equalizing is not possible, the excavated material is either wasted along the sides of the cut, or placed in banks, termed **spoil banks,** located at convenient points. When the material from the cuttings is insufficient or unsuitable to form the embankments, the deficiency is made up from borrow pits.

On hillside roads with moderate slopes, the center line of the road is so located that the excavation from the uphill slope will form the embankment on the downhill slope. On steep slopes, it may be necessary, in order to secure stability, to make the road entirely in excavation.

77. Side Slopes.—In the making of cuttings and embankments, the side slopes must be given a certain inclination to prevent slipping. This inclination is fixed by the character and condition of the material and the atmospheric influences of the locality. It should never be greater than the angle of repose of the material. This angle is about 37° for sand and loam, 45° for clay, and 48° for gravel. These angles correspond, respectively, to slopes of about 1.5 : 1, 1 : 1, .9 : 1. Rock will stand with vertical

sides, but it is customary to give the sides a slope of about 1 horizontal to 2 vertical.

In northern latitudes, it is usual to make the slopes on the south side flatter than on the north side. This is done for the purpose of more freely exposing the roadway to the drying action of the sun and the air.

78. The side slope should not be formed of exactly straight lines, but, as shown in Fig. 9, with a concave curve,

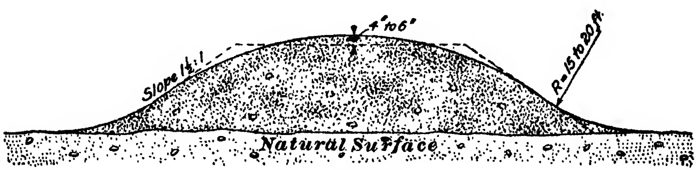


FIG. 9

the flattest portion of which is at the bottom. This form adds to the stability of the slope and reduces the amount of material that is likely to be washed down in a storm.

79. Embankments.—In the formation of embankments, it is customary to specify that they shall be carried up in layers of a foot in thickness and thoroughly compacted by rolling each layer. In practice, however, this is rarely done, because of the great cost and of the fact that the methods generally employed for transporting the excavated material do not readily lend themselves to this form of construction. The excavated material is transported either by dray or by wheeled scrapers, carts, or wagons, and, on very extensive work, by dump cars, hauled on rails by horses or locomotives. The contents of these vehicles are dumped promiscuously, forming isolated heaps, which are roughly leveled by shovelers or grading machines, care being taken that the material is so distributed that the outer edges are maintained at a greater height than the center, and thus to some extent counteracting the tendency to slip.

For the purpose of compacting the material, a corrugated roller weighing about 2 tons and drawn by horses is used. After the bank has been filled to the required height, it is

rolled with a steam roller weighing from 5 to 10 tons, and the depressions produced by the weight of the roller are brought to the required level by adding more material.

80. In making embankments on hillsides, the surface of the ground is usually cut in the form of steps, as shown in Fig. 10. The purpose in this is to counteract the tendency

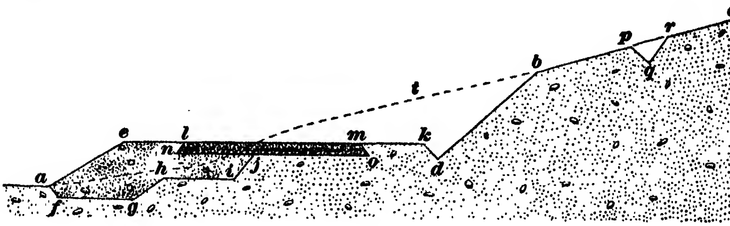


Fig. 10

of the freshly excavated material to slide down the hill. On very steep slopes, it is also necessary to build retaining walls, as shown in Fig. 11.

81. In Fig. 10, the line *atbc* represents the original surface of the ground; *bd* is the slope of the excavation made with an inclination of 2 feet horizontal to 1 foot vertical; *ae* is the slope of the embankment made with an inclination of $1\frac{1}{2}$ feet horizontal to 1 foot vertical. The portion *afghij* shows the manner in which the original

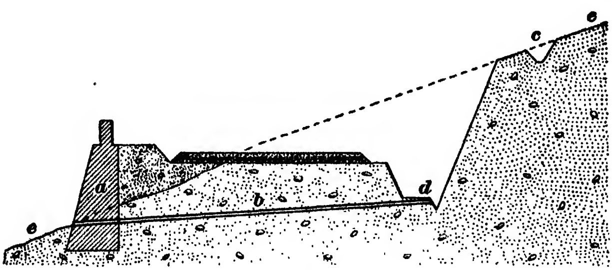


Fig. 11

surface is prepared to receive the base of the embankment. The side *af* varies from 6 to 12 inches in height, and is sloped inwards to form an abutment for the toe of the embankment. The parts *fg* and *hi* vary in width according

to the width required for the embankment, and may be level or sloped inwards. The slopes *g h* and *i j* vary in height from 6 to 12 inches, and have an inclination of 2 to 1. The line *e k* is a section of the surface of the finished road. The broken stone or gravel forming the wheelway is *l m o n*; *k d* and *d b* are the slopes of the side ditch, the depth and width of which varies from 1 to 4 feet, according to conditions; the sides *k d* and *d b* have a slope of $1\frac{1}{2}$ or 2 to 1. *p q r* is a catch-water ditch placed 8 or 10 feet from the edge of the slope to intercept or check the velocity of the surface water flowing down the hill, and prevent it from damaging the slope of the roadway excavation. The depth and the width of this ditch vary according to the amount of water to be conveyed away.

Fig. 11 is a cross-section of a hillside road, in which *a* is a retaining wall; *b*, a cross-drain to remove the water from the side ditch *d*; *c*, a catch-water drain; and *e c e*, the original surface.

In constructing embankments over marshes, it is usual to excavate large side ditches, the material from which forms the bank.

82. Protection of Slopes.—The slopes of the embankments and cuttings are protected from the washing effect of rain by a covering of grass sods, or grass seed is sown and properly cared for until a sod is made. When the slopes are exposed to the action of flowing water, as along the seashore or the bank of a river, they may be protected from injury by a dry stone paving.

HIGHWAYS

(PART 2)

DRAINAGE

GENERAL CONSIDERATIONS

1. Water is the greatest enemy of roads. Through its solvent action, it softens and dissolves the materials of which the road is constructed, and by its expansion while freezing disrupts the roadbed by lifting and displacing its component parts. Hence, *the speedy and efficient removal of water is imperative for the preservation of a road.*

2. Drainage may be either **surface** drainage or **subsurface,** also called **subsoil,** drainage. The first provides for the removal of the rain water from the surface of the road, and is necessary on all roads. The second provides for the removal of the underground water; it is required only under certain conditions and for certain kinds of soils; it is indispensable in those places where the roadway intercepts the natural drainage of the country. Much trouble and expense are caused by a neglect of this important detail. A wet substratum cannot give either a good road or a firm, unyielding subfoundation for a road, and will invariably destroy its efficiency under traffic. Where subsoil drainage is necessary, there should be no hesitancy in spending sufficient money to make it efficient, as this will save many dollars in the cost of maintenance.

3. The sandy soils, unless saturated with water, do not present any difficulty in securing a dry and solid subfoundation,

especially if the fall of the natural drainage is away from the line of the road, in which case gutters and side ditches for the removal of the rain water will generally be found sufficient. The clay soils are naturally retentive of water, although they are not readily saturated; when they reach the state of saturation, they become very unstable and are incapable of supporting heavy loads; it is, therefore, necessary to provide a suitable system of subsoil drainage.

Rock requires little attention to drainage, except where the strata are interspersed with seams of clay and are inclined toward the road, in which case means must be provided for the removal of the water in order to prevent slips.

4. The removal of the subsoil water is effected by constructing underground drains or deep side ditches that discharge into the natural streams. The surface water is removed by gutters connected with the side ditches or underground drains. The manner of arranging and constructing the drains and ditches is explained in subsequent articles.

5. Where the road is in embankment, the underground water will not reach the roadbed, and the drains required will be usually for the purpose only of providing a free passage for the surface water from the adjacent land. The size of the drains must be ample to accomplish this; otherwise, the embankment will become a dam, and consequently be liable to damage in time of heavy rain.

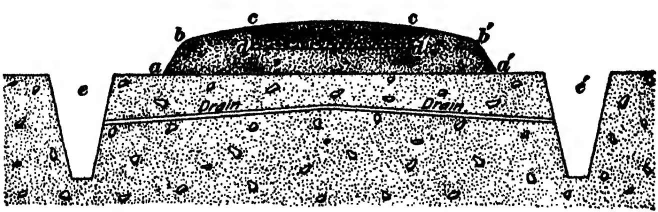


FIG. 1

6. In marshy localities, it may be necessary to drain the ground on which the embankment is to be formed. This is usually effected by side and transverse drains, as shown in

Fig. 1, in which *e* and *e'* are the side ditches; *a b c c' b' a'* is the embankment; and *c c' d' d* is the wheelway.

7. In cuttings, **catch-water drains** (that is, small ditches) should be made along the top of the uphill bank, as described and illustrated in *Highways*, Part 1, to receive the surface water from the higher land and prevent it from washing the slope. These small ditches either discharge into the natural watercourses or are carried down the slope in paved channels and empty into the side ditches.

CONSTRUCTION OF DRAINS

8. Marking and Grading Ditches.—The best method for marking the depth of ditches and trenches for drains is to place grade boards at intervals of 50 feet along the line of the ditch or trench; these boards should be about 1 inch thick and 8 inches wide, and about 2 feet longer than the top width of the trench. They are placed on edge at right angles to the center line, and firmly bedded in the earth. A nail is driven in the center line of the first board, and the elevation of the nail above grade is ascertained. The depth of the excavation from the top of the board is calculated, and its amount is clearly marked on the board; a tack is then placed on each side of the center to mark the point where the side slope of the ditch intersects the natural surface. A stout cord is stretched from the first board to the second, along the center line, and made parallel to the grade line. Then, by using a rod on which the elevation of the cord above grade is marked, points of the grade line are determined by simply holding the rod vertical and in such a manner that the mark will coincide with the cord, in which case the bottom of the rod will indicate a point in the grade line. The cord is made parallel to the grade line by making the top of the second board the same elevation above grade as the first, or, if necessary, by fastening to the second board an extra piece projecting above or below it, of sufficient length to have its top or bottom at the same elevation above grade as the top of the first board.

The method is illustrated in Fig. 2, where *de* is the surface of the ground, *fg'* is the grade line, and *a* and *b* are two points 50 feet apart. Suppose that the elevation of the top of the board at *a* is 3½ feet above grade, that is, above *fg'*, and that the rate of grade is 2 per cent. Then, the grade line is 1 foot higher at *b'* than at *a'*; and, therefore, to have the cord *gr* parallel to *fg'* it is necessary that *r* should be 1 foot higher than *g*. An extra board *c* is nailed to the

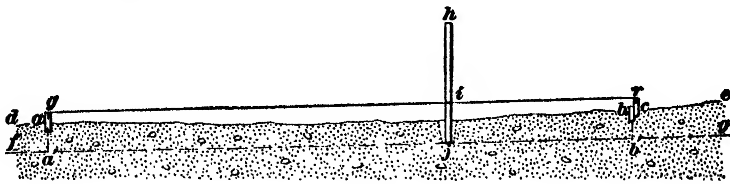


Fig. 2

board *b*; its top *r* is made 1 foot higher than the top *g* of *a*, and then the cord is stretched between the tops of the two boards. A mark *i* is set on a rod *hj* at a distance from the bottom of the rod equal to the elevation of *g* above grade, which in this case is 3½ feet. Any rod or pole will do for this purpose, but a leveling rod is preferable. When the rod is held vertical so that *i* is on the cord *gr*, as shown in the figure, its bottom *j* will be on the grade line.

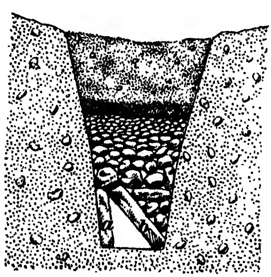


Fig. 3

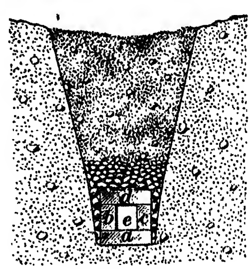


Fig. 4

9. Box Drains.—Where stone is abundant or can be procured cheaply, it is employed in the construction of drains in the manner shown in Fig. 3. The drain is formed by first digging a trench about 2 feet wide, to the depth required to secure the proper fall or grade; the bottom is

carefully graded to a uniform slope, and then large flat stones *a* and *b* are placed to form a triangular passage for the water. The ditch is filled to about one-half its depth with field stones of various sizes, the smaller sizes being placed on top; on the stones is placed a layer of sod with the grass side down; if sod cannot be procured, hay or fine brush may be used instead. The ditch is then filled with earth. This form of drain is called a **box drain.**

10. Box drains can be made with bricks instead of stones, as shown in Fig. 4. Bricks *a*, *b*, *c*, *d* are placed in the bottom of the trench in the positions shown, so as to form a channel *e* for the water: the trench is then filled with earth.

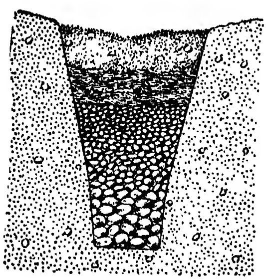


FIG. 5

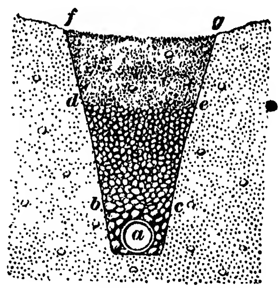


FIG. 6

11. Gravel Drains.—Where gravel abounds, the larger pebbles are used to form a drain in the manner shown in Fig. 5. In this type of drain, the ditch is excavated as just described, and filled with gravel to a depth of 1 or more feet, the largest pebbles being placed at the bottom, and the smallest ones at the top. The gravel is covered with sod, hay, or brush, and the trench is then filled to the top with earth.

12. Tile Drains.—The tile drain shown in Fig. 6 is formed of round, porous (unglazed) drain tiles, laid in the bottom of the ditch, after the latter has been excavated to the required depth and grade. The ditch is then filled with broken stone or gravel, and earth. In the figure, *a* represents the tile; *b c e d*, the stone or gravel filling; and *d e g f*, the earth filling. The tiles are laid end to end, and are held in place by stones placed underneath and at the sides. The

joints, being partly open, permit the free entry of the water. Sometimes, collars or rings are used to encircle the joints. These collars, while preventing the entrance of sand and silt into the drain, allow free access to the water.

Tile drains give more satisfactory service than any other kind, but are more liable to injury from frost than either brick or stone. As a protective measure, they should be terminated at both ends in a stone or brick drain, or in a piece of vitrified pipe extending under the roadway 3 or 4 feet. The exposed ends of the drain should be covered with an iron grating or heavy wire netting, to prevent rats and other vermin from entering, building nests, and stopping up the waterway.

13. General Conditions to be Attended to in the Construction of Drains.—The points to be attended to in the construction of all types of drains are:

1. *The Fall or Grade.*—This should rarely exceed 1 inch in 5 feet. Excessive inclination is likely to cause injury by washing in consequence of the high velocity of the water.

2. *The Area of the Drain.*—This should be in proportion to the amount of water to be removed. In using tile drains, 3 inches should be the minimum size.

3. *The Filling.*—In filling the trenches, care must be taken that the material used does not choke or stop the waterway.

4. *The Materials.*—Only durable materials should be employed, as the cleaning or repairing of a drain involves a great deal of expense.

5. *The Depth.*—The drains should be placed at a sufficient depth to accomplish the object sought. A deep drain will be more effective than a shallow one.

6. *The Inlet and Outlet.*—The ends of the drain should be such as to allow free passage of the water, and should be well protected.

14. Arrangement of Subsoil Drains.—The manner of arranging the subsoil drains depends entirely on the condition of the soil, the nature of the underflow, and the topographical conditions. In a flat country, where the soil is

naturally wet and there is no flow to the underground water, it is considered good practice to use two lines of drains, one on each side of the road, as shown in Fig. 7; these discharge

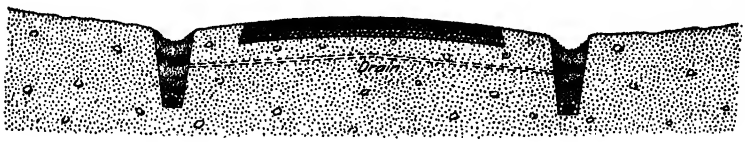


FIG. 7

into the natural watercourses that cross the road. If the amount of water is so great that the two lines of drains may prove ineffective, they may be supplemented by **miter drains** (shown by the dotted lines in Fig. 7) placed about every 15 feet across the road, and discharging into the longitudinal drains. The latter may sometimes be omitted, and the miter drains allowed to empty directly into the side ditches.

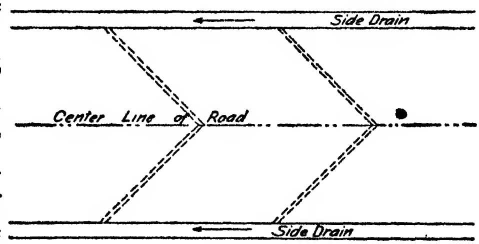


FIG. 8

The miter drains are not placed directly across the road at right angles, but in a V form, as shown in Fig. 8, with the point, or vertex, at the uphill end and in the center of the

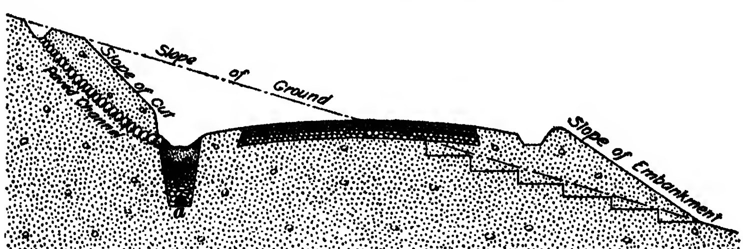


FIG. 9

road. The distance apart at which these drains should be placed must be determined by the nature of the soil and the amount of water. It is generally considered that the action

of an underground drain will not extend beyond 30 feet in sand or gravel nor beyond 15 feet in clay.

In cases where there is a well-defined flow from one side of the road to the other, as in roads located on hillsides, one longitudinal drain placed so as to intercept the flow may be sufficient; such a drain is shown at *a*, Fig. 9.

It is frequently recommended that a single drain be run through the center of the roadway. This location is not advisable: in the case of a break or stoppage, it is expensive to repair or clean out, and traffic will be interrupted. Besides, in the rolling of the road with heavy steam rollers, the drain is liable to be broken.

15. Side Ditches.—The object of side ditches is to carry away the surface water, and sometimes the subsoil water. When not intended to remove the subsoil water, they need not vary in depth more than from 1 to 2 feet, and in width more than from 3 to 6 feet. When the ditch is required to carry the subsoil water, its depth and width will be controlled by the nature of the soil, the position of the outlet, and the amount of water to be carried.

The sides of the ditches should be formed with slopes not steeper than 1 vertical to 1½ horizontal, and, if the conditions will permit, flatter slopes may be employed. The grade should have a uniform fall to the outlet. If the slope is very steep, it may be necessary to pave the bottom of the ditch with stones to protect it from injury in time of heavy rainfalls. The alinement should be straight as much as possible; where angles occur, they should be rounded off with a curve of as large a radius as practicable.

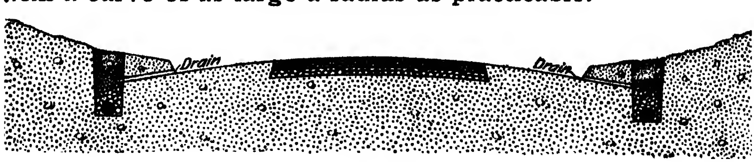


Fig. 10

16. As deep side ditches are both dangerous and expensive to maintain, it is advisable to construct either a stone or a tile drain at the depth required, refill with stones or

earth, and form a shallow ditch on the surface, with inlets for the surface water at suitable intervals. This form of construction is shown in Fig. 10.

17. In cutting, the open ditch is liable to be filled with the loose material washed down from the slope. A berm 3 or 4 feet wide, placed between the top of the slope and the ditch, will afford some protection. If there is a footpath, the berm may be omitted, or a covered drain may be used.

18. On steep grades, it is a common practice to build **water brakes** (mounds of earth or stone varying in height from 6 inches to 2 feet) diagonally across the surface of the road, to turn the water that runs down the surface of the road into the side ditches. On a properly constructed road, they have no place and should not be used: they are an inconvenience and a danger to travel. The surface of the road should have sufficient lateral rise to throw the surface water into the side ditches.

CONSTRUCTION OF ROADS

NATURAL ROADS

19. The term **natural road** is applied to any road formed on the natural surface of the earth. Natural roads consist of either clay, loam, or sand and gravel, and occasionally of rock. Under favorable conditions, these roads furnish a sufficiently satisfactory wheelway for light traffic, but in the presence of water the clay and loam surfaces become nearly or entirely impassable. The sand roads are improved by moisture, while the gravel and rock surfaces, although not seriously affected by water, are more or less disintegrated by the action of frost.

It may be well here to remark that comparatively few of the natural roads throughout the country are as good as they could easily be made. By reason largely of improper location, neglect, and insufficient drainage, the average country road is in a condition far from satisfactory during a large

part of the year. By changing the location and providing drainage where necessary, and by prompt and systematic repairs, the condition of natural roads may be greatly improved without much additional expenditure. The intelligent improvement of such roads is a subject worthy of more attention than it has yet received.

In the formation of natural roads, each soil requires different treatment to produce satisfactory results. The best methods of treatment are described in the following articles.

20. Sandy Soils.—In sandy soils, the natural porosity is generally sufficient to remove the surplus water, and subsoil drains are not necessary. Side ditching, beyond a slight depth to carry away the surface water in long rainy spells, is not desirable, as it tends to hasten the drying of the sand, which is to be avoided, for the reason that a sand road is in its best condition when moist. When clay is available, a coating 6 inches thick, spread over the sand and mixed with it by harrowing, will produce a good roadway.

Sand roads should be as narrow as practicable, and the sides should be lined with as much vegetation as possible. Trees along the sides will aid in keeping the surface moist, and the falling leaves will assist in binding the sand together. The spreading of straw, hay, or sawdust over the surface will greatly improve the road.

21. Clay Soils.—In clay soils, the first essential is thorough drainage of the subsoil by either subsoil drains, deep side ditches, or both. The surface of the portion intended for the wheelway should be cleared of all vegetable matter, then graded and formed to a suitable cross-section by means of a road grader. If sand is available, the clay surface should be plowed, then covered with a layer of sand 6 inches thick, then harrowed, and finally rolled. This will provide a good wheelway during dry weather. If sand is not available, the clay may be improved by burning it, and then spreading and rolling it well. Trees and vegetation along the sides should not be permitted, as they exclude the sun and keep the roadway damp and consequently muddy.

22. Both sand and clay roads may be much improved by the application of crude petroleum oil: that having an asphaltic base is the best. The oil is applied by sprinkling while the road is dry, mixing it with the earth by harrowing, and then compacting it by rolling.

BROKEN-STONE ROADS

23. General Considerations.—A broken-stone road consists essentially of a layer or wearing surface composed of fragments of broken rock spread on the previously prepared natural soil, and consolidated to a firm uniform surface by rolling with steam rollers. Where broken stone is procurable at a reasonable price, it furnishes the best material for surfacing country roads, as regards efficiency, first cost, and expense of maintenance. Its main disadvantage is the formation of mud and dust; and, if the stone is not carefully selected, the surface is liable to be disintegrated by both frost and drought.

24. To secure satisfactory results, certain essential points must be observed. The stone must be of suitable quality, and must be placed on a suitable roadbed. The bed must be thorougly drained, and all disintegrated or worn-out material and vegetable matter must be removed. The subgrade must be brought to a uniform surface, free from hollows, and must be thoroughly consolidated. The voids in the mass of the broken stone must be eliminated by rolling and by adding fine dust; this dust should not be mixed with the stone, but should be applied after the stones have received a slight compaction by rolling. The broken stones should not be left loose to be compacted by the traffic, but should be consolidated by rolling with a roller of suitable weight to bring each piece of stone into close and firm contact with the adjacent pieces.

25. Classification of Broken-Stone Roads.—Roads constructed of broken stone are commonly classified as **macadam roads** and **telford roads**. These names are

applied to distinguish two systems of construction originated, respectively, by John London Macadam—an able Scotch road maker, who, in 1816, began advocating an improved system of road making—and Thomas Telford—an eminent English engineer whose work as a builder of improved roads began in 1820. The appearance of the completed roadway is practically the same in both systems, the distinguishing features being in the foundation.

FIG. 11

Macadam's system consists essentially in spreading and compacting one or more uniform layers of suitable rock broken into pieces of nearly uniform size directly on an earth foundation that has been previously formed to the proper grade and cross-section and thoroughly compacted by rolling. A cross-section of a macadam road is shown in Fig. 11.

Telford's system is much the same as Macadam's, except that the layer of broken stone forming the wearing surface is spread on a paved foundation. This paved foundation is formed by blocks of stone from 3 to 8 inches in depth, set close together on their broadest edges. The cross-section of a telford roadway is shown in Fig. 12. The blocks of stone are set on the earth foundation, and their sizes are graduated according to their position, as shown in the figure.

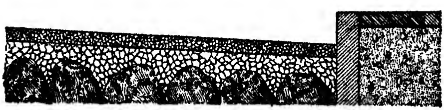


FIG. 12

Each of these systems has its place in the successful construction of roads. The choice depends entirely on the character and condition of the natural soil. If this is composed of clay, not easily drained, a telford foundation will be preferable; but, if the soil is easily drained, a foundation will not be required, and the macadam system will be found the cheaper and better adapted to the conditions.

26. Quality of the Broken Stone.—A good quality of stone should be selected for road material. The stone should be hard, tough, and durable, and should have good binding properties. It should offer a high degree of resistance to abrasion, but need not necessarily be of high crushing strength. It should also be of such quality as not to soften or deteriorate under the action of the atmosphere. Toughness and resistance to abrasion are two very essential qualities.

27. The varieties of rock most suitable for road metal are trap, syenite, granite, chert, limestone, mica-schist, and quartz. These are named in the order of their relative values. Sandstone, clayey slate, and rock of indurated clayey material are not suitable for this purpose. Sandstone has practically no binding properties; the fragments do not bind together to form a solid mass, but remain simply an accumulation of separate fragments, which soon become ground and crushed into sand by the traffic. Clayey stones have poor binding qualities, and when saturated with water become very soft and are easily crushed into mud.

28. The problem of selecting a suitable stone for a given road consists in selecting the rock that will make a durable and smooth surface at the lowest cost for construction and maintenance. To accomplish this, it is necessary to consider the particular conditions applying to the road. The amount and the character of the travel are very important factors. For extensive heavy traffic, resistance to abrasion is more important than cementing power, because the traffic tends to consolidate the stone. Light travel does not require a hard stone, but one that cements or binds well.

Another very important factor is the climate. In localities subjected to heavy rains, droughts, and extremes of temperature, good binding quality is essential; where opposite conditions prevail, the binding quality is not so important.

29. Tests of Stone.—To form an opinion as to the probable endurance of a stone for road purposes, the best test is actual use in the road; but, as this is not always

possible, on account of the time involved, more rapid methods must be employed. The laboratory tests generally used include a physical and microscopic examination, and the determination of the specific gravity, the absorptive capacity, the resistance to freezing, the resistance to abrasion, the crushing strength, and the cementing capacity. A chemical analysis is sometimes made, and often furnishes information of importance. These tests are made as described in *Stone and Brick*.

30. Size of the Broken Stone.—Before being spread on the roadway, the stone should be broken into small fragments. The proper size for these fragments usually depends to some extent on the nature of the material. The harder and tougher the material, the smaller should the fragments generally be. A common rule requires that the stone shall be broken small enough to pass through a $2\frac{1}{2}$-inch ring. It is also a not uncommon practice to use somewhat larger pieces in the bottom courses of the roadway than at the top, the stones at the bottom being from 2 to 3 inches in greatest dimension and those at the surface not more than 2 inches. This is probably a good practice, though it may be doubtful whether it is sufficiently advantageous to warrant the additional expense of separating the sizes.

Opinions differ as to the better practice. Some advocate the use of stone of uniform size, while others believe that the best results are obtained by using sizes varying from a maximum of about 2 inches down to a minimum of about $\frac{3}{4}$ inch. The fact is, probably, that stone of uniform size will wear more evenly, while variable sizes and the presence of smaller fragments facilitate the binding together of the mass.

31. Breaking the Stone.—The stone is broken to the required sizes in machines called **rock breakers** or **rock crushers**. Two types of machines are in common use: the **jaw breaker** and the **rotary crusher**. The jaw breaker consists of a heavy cast-iron frame carrying a movable jaw at one end. By means of a togglejoint and eccentric, the jaw is moved backwards and forwards through a

short distance by a steam engine. The stone to be broken is fed in between the jaw and the frame as the jaw recedes from the frame, and is broken or crushed as the jaw approaches the frame. The size of the broken stone is determined by the distance between the jaw and the frame at their lower edges.

The rotary crusher consists of a conical cast-iron or steel shaft revolving inside a conical or bell-shaped case; the rotating mechanism is so arranged that the conical shaft alternately approaches and recedes from the surface of the case; this movement causes the stone to be crushed as it passes downwards between the shaft and the case. Provision is made for adjusting the amount of movement of the shaft by which the size of the broken stone is regulated.

Both types of machines are made in a variety of sizes, ranging in capacity from 10 to 200 tons per day.

32. Screens.—The broken stone passes from the crusher to a revolving cylinder called a **screen**, perforated with holes according to the size of stone required. The screens are commonly divided into three sections: the first section has holes 1 inch in diameter; the second has holes 1½ inches in diameter; and the third has holes 2½ inches in diameter. The stone enters at one end, and in passing over the perforations is separated into the different sizes according to the size of the holes in the screen. The stone falling through these holes is received in bins and stored until required. Stones too large to pass through the perforations pass over them and leave the screen at the lower end, which is open.

33. Thickness of Stone Covering.—The necessary thickness of the covering of broken stone depends on the nature of the foundation, the thoroughness of the drainage, the completeness of the binding, and the character of the traffic to be sustained. Less thickness will be required for light travel than for heavy travel. A covering well bound together need not be as thick as an imperfectly bound covering. A firm, thoroughly drained foundation does not require as thick a covering as a less perfect foundation. The thickness of the covering of broken stone should not be

less than 4 inches, and a thickness greater than 12 inches is seldom required. Macadam considered 10 inches of well compacted broken stone on a solid, well-drained earth founda tion sufficient for a roadway sustaining the heaviest traffic. A thickness of from 8 to 10 inches is generally considered sufficient.

34. Preparing the Foundation.—The earth foundation of the roadway, which is sometimes called the **road-bed,** should be formed to the proper grade and cross-section and thoroughly compacted by rolling before putting on the covering or surface material. When the foundation is finished, its surface, which is commonly called the **sub-grade,** should be at a distance below the grade line equal to the intended thickness of the covering material. The earth foundation should slope from the center each way

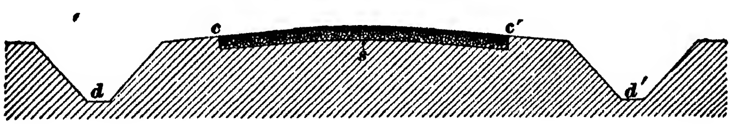


FIG. 13

toward the gutter, its form being the same as that of the cross-section of the road surface, as explained in *Highways*, Part 1.

Where the surface of the completed roadway is not materially higher than the natural surface of the ground, the roadbed is formed by excavating a trench of the proper width and depth to receive the covering material. This is shown in Fig. 13, which is the cross-section of a macadam road for which the drainage is effected wholly by the deep side ditches *d* and *d'*.

In some cases, flat stones are set on edge along the outer edges of the roadway, as at *c* and *c'*. These stones are variously called **edge stones, shoulder stones,** and **border stones.** They are omitted when the width between the edge of the trench and the edge of the ditch is 8 feet or more. In Fig. 13, *s* is the subgrade, or the surface of the foundation.

35. In preparing the foundation, the excavation should be made sufficiently deep to remove the surface soil and all material containing vegetable mold, roots, and decaying matter of any kind. Where practicable, the excavation should be carried downwards until a satisfactory material—such as firm gravel, compact sand, or true hardpan—is reached. If a consolidated undersoil or hardpan is encountered a short distance below the surface, it should generally not be broken, even though it is somewhat above subgrade, as it will usually afford a better foundation than can be obtained at a greater depth.

If the trench extends below subgrade, it should be brought up to subgrade by filling in with suitable material, such as gravel, stone, or the material with which the road is to be surfaced.

36. Before the covering of stone is applied, the foundation should be thoroughly compacted by rolling with a heavy roller. After a thorough rolling, the surface will be more or less uneven. The irregularities in the surface must be removed by cutting down the high places and filling in the hollows, after which the rolling is resumed. This process is continued until a firm and even surface is obtained. On the foundation thus prepared, the covering material is spread.

37. Applying the Broken Stone.—The broken stone is hauled on the roadbed in wagons or other vehicles, dumped, and spread broadcast over the bed by the use of stone forks, and is brought to a uniform thickness of about 5 inches by the use of stone rakes. Carts called **spreading carts** have been recently introduced, which place the stone where required and automatically spread it in layers of any desired depth.

To secure uniformity of thickness, grade stakes are placed at suitable intervals along the margin of the road. The tops of these stakes indicate the finished crown, and the height of each layer of stone is marked on the sides. Stout cords, stretched from stake to stake, are used as a guide for the workmen.

38. After the layer of stone has been spread for some distance, and to the full width of the roadway, the rolling is begun. The roller is preceded by a sprinkling cart, which distributes water over the layer of stones. The rolling is commenced at one edge of the road, and is carried on opposite sides alternately in such a manner that the strip first rolled is overlapped at each trip, until the center is reached. As the rolling progresses, the hollows that are formed are filled with stone. The rolling is continued until there is no perceptible motion among the stones. A second course or layer is then applied, and the process of rolling and sprinkling repeated.

39. When the last course has been properly compacted, the binder is spread over its surface to a depth of $\frac{1}{2}$ or $\frac{3}{4}$ inch, and sprinkled; the rolling is repeated and continued until the consolidation is complete. As a test of this condition, if a small stone is placed on the surface and the roller passed over it, it should be crushed before being driven into the road surface.

40. The weight of the roller and the manner of its application affect, to a certain extent, the enduring qualities of the stone. To secure the best results, the weight of the roller must be determined by the character of the stone to be compacted. If the stone is soft and friable, as limestone, a roller weighing about 5 tons should be employed, as a heavier roller will crush the stone to dust. For the harder stones, as trap, a roller weighing from 10 to 12 tons may be used.

41. Binder.—The stone dust spread on the surface of the broken stone is called the **binder.** The object in using a binder is to completely fill the voids that remain after the roadway has been compacted with the roller, and that no amount of rolling will entirely eliminate. The amount of binder must be only slightly in excess of that required to fill the voids; a larger quantity than needed for this purpose will be injurious. The voids in a well-compacted mass of stone amount to about 25 per cent. of the mass, and a

corresponding amount of binder must be used to fill them. The amount of water used must be moderate; it is used simply as a lubricant to assist the compacting of the stone. A large quantity will cause the stone to be forced into the roadbed, forming a weak and defective road that under traffic will produce much mud and dust.

OTHER ARTIFICIAL ROADS

42. For the improvement of the natural roads and the furnishing of a hard smooth surface, various materials are employed, ranging from sawdust to stone. The selection of the material depends entirely on the cost and the facility with which suitable material can be procured. In localities where stone and gravel do not exist and can only be obtained at excessive cost, advantage must be taken of such materials as are found in the vicinity of the road, or such as can be had at a reasonable cost.

43. Sawdust and Tan-Bark Roads.—Spent tan is of some service, and wood fiber in any form is excellent material for the improvement of sand roads. The best fiber is the sawdust made in sawing shingles by those machines that cut lengthwise of the fiber into the side of the block. The sawdust is first spread on the road 8 or 10 inches deep, and it is then covered with sand to protect the road from fire. The sand also tends to keep the sawdust damp. The dust and sand soon become hard and packed, and the wheels of the heaviest wagons make but little impression on the surface, which appears to be almost as solid as a plank road, but is much easier for teams. A surface prepared in this manner on a proper foundation will remain good for 4 to 5 years, and will then require renewing in some parts only.

The ordinary lumber sawdust is not so good, but if mixed with planer shavings may serve fairly well. Any strong fibrous substance, and especially one that holds moisture—such as the refuse of sugar cane or sorghum, and even common straw, flax, or swamp grass—will be found useful in the construction of tolerably good roads.

44. Corduroy Roads.—Roads built of poles or logs laid across the roadway are called **corduroy** roads, because of their corrugated or ribbed appearance. These roads should never be built where it is possible to secure any other good material, except in cases of emergency, such as when it is necessary to build a temporary road for the moving of artillery and commissary trains through swampy regions in time of war. Logs are superior to poles for this purpose, and should be used when possible.

45. Shell Roads.—In many of the southern American states, stone and gravel suitable for road surfaces do not exist, and can only be procured at a prohibitive cost. As a substitute, oyster shells, which can be had in abundance and at a very low cost, are used. These shells, when carefully maintained, form an excellent surface for light traffic.

The earth surface of the roadway is graded and finished to a suitable form, and provision is made where necessary for its drainage. The shells are spread loosely over the prepared surface. Under the action of the traffic, they are speedily crushed and compacted into a smooth surface. To keep them in good condition requires constant watchfulness. When ruts or depressions occur, they must be filled up with broken shells, and the ditches and drains must be kept clear so as to afford a free passage for the water.

46. Chert.—In some of the southern American states, notably in Alabama, a silicious material called **chert** is extensively employed for covering the roads. It is spread on the earth's surface to a thickness of about 5 inches and then sprinkled and rolled.

47. Charcoal.—In localities where wood is abundant and cheap, charcoal, made by burning wood in heaps along the surface of the proposed road, has been used with good results.

48. Furnace Slag.—Slag and cinders from smelting furnaces furnish a very durable road material, especially when mixed with limestone dust or clay.

49. Gravel Roads.—Where gravel of suitable quality is procurable, it forms an excellent road surface at a cost of from one-quarter to one-half that of broken stone, and under moderate traffic can be maintained in good condition more cheaply than a broken-stone road under similar conditions.

The best gravels for road purposes consist of fragments of undecayed rock of a trappean nature cemented or held together by ferruginous clay. Gravel composed mainly of white granite pebbles is not of much value as a road material: the pebbles are generally very smooth, and hence possess little if any binding power. Gravel consisting of fragments of granite, limestone, or mica-schist, while of variable quality, makes in the absence of more suitable material a fair surface for light travel.

50. The essential requisite of a gravel, to form a satisfactory road surface, is that it will bind well together. That it may possess this property, the gravel must consist of pebbles of all sizes, ranging from the largest, which should not exceed 2 inches, to the smallest, which should be about the size of a pea. Each size should be in just sufficient proportion to fill the interstices or voids in the next larger size. If the gravel is not naturally graded in these proportions, the grading must be done artificially by screening and mixing the different sizes. If the gravel is deficient in fine dust, sufficient must be added to fill the small voids that cannot be filled by the smaller pebbles. This fine material may consist of sand, clay, or loam. When the gravel naturally contains an excessive amount of clayey or loamy matter, this matter must be removed by washing. The permissible amount of clay or loam may range from one-eighth to one-fourth of the bulk.

Gravel composed of stones of angular form, such as is found in pits, is much better for road purposes than that composed of round or oval pebbles, such as is commonly found in the beds of streams and on the seashore.

51. The thickness of the gravel covering will depend on the extent and weight of the traffic. It ranges from 4 inches

for very light traffic to 12 inches for the heaviest traffic. The gravel is spread on the prepared roadbed in layers 4 inches thick, and each layer is compacted by a roller of suitable weight, a heavy roller being used for small and a light roller for coarse or large gravel. A small amount of water should be sprinkled over the gravel in advance of the rolling; and, when all the layers are compacted, a small amount of clay or loam may be spread over the surface and rolled without water, after which the roadway may be opened to the traffic.

MAINTENANCE OF ROADS

52. Natural and artificial roads are alike in one particular: they require constant attention to maintain them in good condition. The disintegration and wear of roads are caused: (1) by the action of the traffic, which consists of the abrasive effect of the wheels and horses' feet; and (2) by the action of natural forces, comprising heavy rainfalls, winds, changes of temperature, frost, and chemical disintegration of the material composing the road surface.

The maintenance of a road requires constant attention to counteract the destroying effects enumerated, and consists in keeping the surface smooth by the elimination of ruts and hollows, and the side ditches, drains, and waterways open so as to afford a free passage for the water.

53. The natural roads are kept in good condition by the frequent use of the road scraper and roller. Immediately after a storm, all breaks in the surface should be repaired, and the entire surface compacted by rolling. In the fall of the year, the surface of the road should be put in condition, by harrowing, scraping, and rolling, to withstand the ravages of winter weather.

54. Artificial roads are kept in good condition by removing dirt and mud, by the prompt filling of ruts and depressions, and by the application of new material to replace the wear caused by the traffic. When any quantity of new material needs to be applied, the old surface should be broken up

either by hand picks or by a scarifier, and then the new material should be spread, sprinkled, and rolled.

During a long spell of dry weather, broken-stone roads used by light traffic are subject to a loosening of the stones, which is termed **raveling.** Various expedients have been tried to prevent the road from getting into this state; the one that gives any degree of satisfaction is the sprinkling of clean sand over the surface as often as needed.

In the spring, after the frost is out and before the road has become dry, a thorough rolling with a steam roller will materially aid in keeping the road in good condition during the summer.

As a general rule, it may be stated that the repairs of broken-stone roads should begin the day the roads are opened to traffic. The attention they receive during the first few months of use will contribute largely to their endurance and usefulness. It has been proved by experience that a more enduring and useful road can be secured by a system of continuous small repairs than by leaving the road uncared for until it has fallen into a state of general derangement, and then making extensive repairs.

SPECIFICATIONS AND CONTRACT

55. Before commencing the work of construction, it is necessary to prepare for the guidance of the constructor a set of specifications describing the character of the materials to be used and the manner in which the work is to be prosecuted. If the work is to be done by a contractor, a form of proposal and contract will have to be prepared. Typical forms of advertisement, proposal, contract, bond, and specifications are given in the following articles.

56. Advertisement.—

OFFICE OF COUNTY COMMISSIONERS OF NASSAU COUNTY

Sealed proposals addressed to the County Commissioners of Nassau County will be received up to 12 o'clock noon, April 15, 1907, when they will be publicly opened and read, for the improvement of the county road between Merrick and Bellmore, in Nassau County.

The work has been divided into four sections, as described and shown in the plans and specifications to be seen at the office of the County Commissioners at Merrick, and will be known as Sections 1, 2, 3, and 4, respectively.

Separate bids must be made for each section desired, but a single bid may be submitted for the whole work, if accompanied by bids for each section.

Bids for doing the work must be in accordance with the plans and specifications approved by the County Commissioners and on file at their office.

The County Commissioners of Nassau County expressly reserve the right to reject any or all bids.

Before the contract is awarded, the successful bidder or bidders will be required to furnish a bond of five thousand dollars ($5,000) for the faithful performance of the work in accordance with the aforesaid plans and specifications.

BY ORDER OF COUNTY COMMISSIONERS OF NASSAU COUNTY.

57. Proposal.—

TO THE COUNTY COMMISSIONERS OF NASSAU COUNTY:

For the improvement as hereinafter specified of the section of the county road between Merrick and Bellmore, located in Nassau County, State of New York. *Made by* JOHNSON & HOLLAND.
Address: Jamaica, N. Y.

The undersigned hereby declare that they have carefully examined the annexed form of contract and specifications, and the drawings forming a part of the same, and have to their satisfaction examined the road on which improvement is proposed, and agree to furnish all tools, machinery, and other means of construction that may be necessary, and to do all the work and furnish all material as called for and in the manner provided by annexed contract, specifications, and drawings thereto, and requirements under them of the Engineer, for the following prices, to wit:

1. *For excavations* of all descriptions, except ledge rock, including all grubbing, clearing, and incidental work, 50 cents per cubic yard.

2. *For ledge-rock excavation*, including all incidental work, $3 per cubic yard.

3. *For excavation for borrowed material* when outside the line of the road, including all incidental work not exceeding $\frac{1}{2}$ mile haul, 60 cents per cubic yard.

4. *For shaping roadbed*, including all clearing, grubbing, forming of gutters, and all incidental work not requiring a change in the present grade of the roadbed of over 8 inches, 10 cents per square yard.

5. *For loosening and shaping present stone surface*, so as to form a proper cross-section, not including additional broken stone that may be required, 5 cents per square yard.

6. *For telford foundation* in place, including all materials and incidental work, 60 cents per square yard.

7. *For crushed stone* in place, including all materials, rolling, and incidental work, as provided for in the specifications, measured in the carts:

From Quarry A:

For 1st and 2d Sections, $1.00 per cubic yard
For 3d and 4th Sections, $1.25 per cubic yard

From Quarry B:

For 1st and 2d Sections, $1.30 per cubic yard
For 3d and 4th Sections, $1.50 per cubic yard

From Quarry C:

For 1st and 2d Sections, $1.50 per cubic yard
For 3d and 4th Sections, $1.75 per cubic yard

8. *For all vitrified drain pipe*, including all materials, excavations (except ledge rock), and incidental work:

24-inch pipe	$2.50 per foot
18-inch pipe	$2.00 per foot
12-inch pipe	$1.00 per foot
6-inch pipe	40 cents per foot

9. *For iron pipe*, including all materials, excavation (except ledge rock), and incidental work:

12-inch pipe	$1.95 per foot
18-inch pipe	$3.25 per foot
24-inch pipe	$4.85 per foot

10. *For cement rubble masonry*, including all materials and incidental work, $5 per cubic yard.

11. *For dry rubble masonry*, including all materials and incidental work, $3 per cubic yard.

12. *For extra work*, ordered in writing by the County Commissioners, including use of all tools, actual cost plus 10 per cent.

13. *For materials* furnished by contractor, actual cost as shown by paid vouchers.

14. *For laborers*, 15 cents per hour.

15. *For single team and driver*, 10-hour day, at county rates, plus 10 per cent.

16. *For double team and driver*, 10-hour day, at county rates, plus 10 per cent.

Accompanying this proposal is a certified check for $1,000, drawn on the Freeport National Bank, payable to the County Commissioners of Nassau County, which shall become the property of said Commissioners, should this proposal be accepted by said Commissioners, and the undersigned fail to execute the contract with said Commissioners; otherwise, the check will be returned to the undersigned.

[SIGNED] *Name:* JOHNSON & HOLLAND.
Date: April 15, 1907. *Address:* Jamaica, N. Y.

CONTRACT

58. Preamble.—

STATE OF NEW YORK

COUNTY COMMISSIONERS OF NASSAU COUNTY

This contract for improving all the sections of the county road between Merrick and Bellmore, in Nassau County, made and concluded on the 20th day of April, 1907, between the County Commissioners of Nassau County, party of the first part, and William Johnson and James Holland, trading as Johnson & Holland, party of the second part.

WITNESSETH: That, in consideration of the sums hereinafter mentioned to be paid by the party of the first part, and penalty expressed in the bond of even date with these presents and annexed hereto, the said party of the second part agrees with the said party of the first part, at their own proper cost and expense, to do all the work and furnish all materials necessary to improve the portions of the county road between Merrick and Bellmore in Nassau County, in accordance with and as described in the specifications and plans attached hereto, and in full compliance with the terms of this agreement.

59. Plans, Profiles, and Specifications.—The plans, profiles, and specifications are hereby made a part of this contract, and will be held to cover any and all work that can reasonably be inferred as needed for a complete and workmanlike job. And it is understood that no advantage will be taken of discrepancies found in any drawing or specification.

If any doubt or dispute arises in regard to interpretation of the specifications, plans, or contract, the same shall be referred to the Engineer, whose decision shall be final.

60. Changes in Plans.—The right is reserved to make such changes in the plans or specifications as may from time to time appear necessary or desirable, and such changes shall in no wise invalidate this contract. Should such changes be productive of increased cost to the Contractors, a fair and equitable sum therefor, to be agreed on before such changed work shall have been begun, shall be added to the contract price, and in like manner deductions shall be made.

61. Contractors' Liability.—The Contractors assume all risks and liabilities for accidents and damage that may accrue to persons and property during the prosecution of the work by reason of the negligence or carelessness of the Contractors, their agents, or their employes.

62. Subletting Contract.—The Contractors agree to give their personal attention to work embraced in this contract, and not to sublet the same or any portion without the written consent of the Commissioners.

63. Instructions to Foremen.—The superintendents or foremen of any particular portion of the work shall receive and obey the instructions of the Engineer in case the Contractors themselves are not present.

64. Work Begun and Completed.—The work is to be begun within 10 days after the execution of this contract, and to be diligently prosecuted to completion in such order as may be prescribed by the Commissioners.

The Contractors hereby agree to complete the work on or before October 15, 1907, which date may be postponed at the discretion of the Commissioners.

The County Commissioners hereby agree to close the road to travel, section by section, as the work progresses; but at no time will more than one section be closed unless the County Commissioners should so direct.

65. Laws and Ordinances.—The Contractors and those under them shall conduct the work in such a manner as to fulfil all the requirements of state, county, or town laws and ordinances applying to the work in hand, and they shall take such necessary precautions as will guard against accident or loss of life.

66. Clearing Up.—The Contractors are to leave the road in a neat condition, and to remove and clear up all rubbish and surplus material.

67. Incompetent and Disorderly Persons.—Should any person employed by the Contractors appear incompetent or disorderly, he shall be immediately discharged on request of the Engineer, and shall not be employed again on the work.

68. Definitions.—Where the word "Commissioners" is used in this contract, it shall be understood to mean the Board of County Commissioners for Nassau County, party of the first part to this contract, or their authorized representatives, limited by the particular duties intrusted to them.

Whenever the word "Contractors" is used, it is understood to mean the persons that have entered into this contract as party of the second part, or their authorized representatives.

Whenever the word "Engineer" is used, it is understood to mean the Highway Engineer of the County of Nassau, or his authorized representative.

69. Payments.—Payments will be made by the Commissioners to the Contractors on work done under this contract as follows:

On monthly estimates furnished by the Engineer, less 10 per cent. due on the said estimate; said 10 per cent. is to be retained until a section is completed, when all money due on that section will be paid on certificate from the Engineer that work on said section has been completed in accordance with the specifications.

In witness whereof, the parties hereto have set their hands, the date herein mentioned. [SIGNED] WM. A. SMITH.

FRED. C. CONWAY.

ROBT. L. RUSSELL.

County Commissioners for County.

JOHNSON & HOLLAND.

Contractors.

70. Extra Work.—On receipt of written orders, signed by the County Commissioners, the Contractors agree to do such extra work and furnish such materials as may be necessary for the same. The Contractors shall receive the actual cost of all materials so furnished, as shown by paid vouchers, and for such labor and teams as are necessary, the price as herein agreed on.

---

71. Bond.—

KNOW ALL MEN BY THESE PRESENTS:

That we, William Johnson and James Holland, as principal, and The National Surety Company, of Washington, D. C., as sureties, are held and firmly bound unto the County Commissioners of Nassau County, State of New York, in the sum of five thousand dollars ($5,000), to be paid to the said County Commissioners or their certain attorney, their successors, and assigns, for which payment well and truly to be made we bind ourselves, our heirs, executors, and administrators, jointly and severally, by these presents.

The condition of this obligation is such that, if the said principal, Johnson & Holland, shall well and truly keep and perform all the terms and conditions of the aforegoing contract for improving the county road between Merrick and Bellmore in Nassau County, on their part to be kept and performed and shall indemnify the said County Commissioners of Nassau County as therein stipulated, then this obligation shall have no effect; otherwise, it shall remain in full force and virtue.

Sealed with our seals and dated this fifteenth day of April, 1907.

[L. S.] WILLIAM JOHNSON.

[L. S.] JAMES HOLLAND.

[L. S.] NATIONAL SURETY COMPANY.

Witness:

F. A. SMITH.

SPECIFICATIONS

72. General Title.—Specifications for improving the county road between Merrick and Bellmore, in Nassau County, beginning at a point near Main Street, Merrick, and extending to a point near Bellmore.

Approximate length of road to be improved, 5.47 miles.

73. Work to be Done.—The Contractors are to furnish all tools, machinery, and labor, and to do all the work in connection with the proposed improvement of said road (except as herein specified), including all grading, draining, and surfacing in accordance with these specifications, and plans and requirements under them of the Engineer. Said plans are to be signed by the County Commissioners of Nassau County and by the Highway Engineer of the said county, and form a part of these specifications. The Contractor is to leave the road and immediate vicinity in a neat and presentable condition ready for use.

74. Estimated Quantities.—The following quantities of the work to be done are approximate only, and are intended principally to serve as a guide in figuring out the bids. The quantities may be subsequently increased or diminished, as may be deemed necessary by the County Commissioners of Nassau County, as hereinafter provided in the specifications.

Excavations (other than ledge)	3,000 cubic yards
Excavation, "borrowed material"	100 cubic yards
Ledge excavation	500 cubic yards
Rubble masonry	100 cubic yards
Rubble masonry laid in cement	200 cubic yards
Brick masonry	150 cubic yards
Vitrified clay pipe:	
6-inch pipe	500 linear feet
18-inch pipe	1,000 linear feet
12-inch pipe	500 linear feet
24-inch pipe	200 linear feet
Iron pipe:	
24-inch pipe	200 linear feet
18-inch pipe	200 linear feet
12-inch pipe	200 linear feet

Shaping roadbed, 30,000 square yards.

Loosening and shaping present stone surface, 2,000 square yards.

Telford foundation, 15,000 square yards.

Crushed stone, 5,000 cubic yards.

75. Earthwork.—The roadbed shall be graded for a width of 20 feet in conformity with the plans, profiles, and cross-sections that accompany and are a part of these specifications.

All materials excavated within the lines of the work and used for filling are to be paid for as excavation only. Materials used for filling brought from outside the lines of the work are to be paid for as "borrowed."

Embankments are to be made in layers, not exceeding 12 inches in thickness, until the proper grade is reached.

All measurements for earthwork are to be made in excavation.

All surfaces and slopes are to be left smooth and neat.

76. Ledge-Rock Excavation.—Only boulders measuring over $\frac{1}{2}$ cubic yard or ledge requiring blasting for its removal shall be classed as ledge rock; nor will allowance be made for ledge-rock excavation more than 6 inches below the subgrade.

77. Rubble Masonry.—Rubble masonry shall be composed of quarry stone free from structural defects and presenting good beds for material of this kind, and of suitable sizes and shapes for the work, so as to give a bond of at least 6 inches, and with sufficient headers to give well-bonded work, the larger stone to be used for foundation purposes.

Covering stone is not to be less than 12 inches thick, laid with close joints, and with the ends overlapping the side walls at least 12 inches.

78. Cement Rubble Masonry.—Cement masonry shall be used wherever directed by the Engineer, and shall consist of sound stone with beds suitable for this class of work. The stone is to be laid in courses not less than 12 inches thick, with alternate headers and stretchers. The joints shall not be over 1 inch wide, and shall be well filled with cement mortar.

Cement mortar is to consist of one part American cement and two parts clean sharp sand; or one part Portland cement and three parts clean sharp sand. The cement is to be kept until used in tight barrels or bags thoroughly protected from all moisture.

No mortar is to be used that has stood over 45 minutes or has taken an initial set or has been retempered.

79. Pipe Culverts.—The trenches are to be excavated to the grade shown on the plan and profile, and as given by the Engineer, so as to insure a true alinement for the pipe.

Care must be taken that each section of the pipe has a firm bearing throughout its length.

All pipe must be sound and free from cracks and distortions.

No other allowance than the price per foot for laying pipes will be made for excavating the trench, except where the Contractor is directed to dig the trench more than 3 feet deep, allowance then being made for all material excavated beyond 3 feet.

80. Shaping Roadbed.—In cuts and fills, unless specially directed, the roadbed is to be graded to a width of 20 feet, and is to be free from all spongy and vegetable matter, roots, and stumps. The roadbed prepared for the broken-stone surface is to be 12 feet wide, and brought to the grade and cross-section shown on the plans, and rolled with a steam roller until firm and hard. All depressions that may appear during the rolling are to be filled with earth and rolled until an even surface is obtained.

Where no change from the present grade of those portions of the road not already surfaced with stone is shown on the profile, the roadbed is to be shaped to the proper cross-section and rolled to a firm smooth surface, before the application of broken stone. The price for this work is to be included in that for shaping roadbed, and is to include all excavation and work that may be necessary for removing slight elevations and contiguous depressions, and also excavation for telford or macadam constructions that do not require a change in the present grade of the roadbed of over 8 inches. The width to be paid for in shaping the roadbed is to be only that covered by the broken stone.

81. Loosening and Shaping Present Stone Surface. Where deemed necessary by the Engineer, the surface of those portions of the roadbed now covered with broken stone is to be loosened and given the proper cross-section; this class of work is to be paid for by the square yard. Should it be necessary after loosening the old roadbed to add more broken stone in order to form the proper cross-section, all extra stone so furnished will be paid for at the price agreed on for the character of the broken stone so used.

The price for loosening the present stone surface is to be allowed only when the present grade remains unchanged, and is not to be allowed on those sections of the road where the old bed is entirely removed in order to reach the proper grade. In this last instance, the only price allowed will be that for excavation.

82. Telford Foundation.—The telford foundation is to be used whenever directed by the Engineer. The roadbed is to be first shaped and rolled as already described and stipulated. The stones for the foundation course shall be sound, with sharp corners, with a depth of 5 to 8 inches, width 3 to 6 inches, and length not exceeding 15 inches. They are to be laid lengthwise across the road, with the broad base down. Protruding corners shall be broken off, and the spaces filled with smaller pieces; the whole is to be rolled until firm. Should any depressions show, they shall be filled with stone and rolled until firm. The interstices must not be filled with earth. The thickness of the telford foundation is to be 8 inches when finished. The price paid for the telford foundation is to include all work and materials necessary to do the work as above described.

83. Surfacing of Telford Foundation.—Broken stone varying in size from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches is to be spread over the telford foundation so as to roll to a thickness of 4 inches, and shall consist of crushed trap rock, unless otherwise directed by the Engineer. Broken stone is to be spread with forks from piles alongside the road or from a dumping board, or it may be spread directly from wagons specially constructed for this purpose; but in no case shall the stone be dumped directly on the foundation course, except that broken stone may be put directly on the roadbed from wagons if the pile of stone is continuous and in the center of the road. After spreading, the broken stone is to be rolled until firm and thoroughly compacted.

84. Finishing Course.—A surfacing of screenings, to consist either of trap-rock screenings or other binding material, as the Engineer may direct, is to be applied in the same manner as specified for the finishing course for macadam construction.

85. Macadam Construction.—Macadam construction is to be used wherever directed by the Engineer or provided for in the plans.

First Course.—The first course is to consist of sound stone broken to sizes varying from $1\frac{1}{2}$ to 3 inches. The thickness of the first course after rolling is to be not less than 4 inches, and shall be thicker than this where specially ordered by the Engineer. The broken stone is to be spread as already described for spreading the surfacing over a telford foundation. After spreading, the stone is to be rolled until firm and thoroughly compacted, and have a cross-section to conform to that shown by the drawings.

Second Course.—The second course shall consist of stones varying in size from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches, and shall be crushed trap rock, unless otherwise ordered by the Engineer. The thickness of the second course is to be 2 inches after rolling, and the manner of spreading is to be the same as provided for the first course. After spreading, it is to be rolled until the stones are firm and thoroughly compacted.

Third Course.—The third course shall consist of trap-rock screenings varying in size from dust to $\frac{3}{4}$ inch. The screenings are to be spread dry and be sufficient to barely fill the interstices, and shall be then swept in, watered, and rolled, after which from 1 inch to $1\frac{1}{2}$ inches of additional screenings are to be spread dry, watered, and rolled until the surface becomes hard and smooth. In no case shall the screenings be rolled in dry. When specially directed by the Engineer, other binding materials than trap-rock screenings may be used, but should be applied in the manner above described. Screenings should be dumped and spread in the manner specified for broken stone.

86. Resurfacing Portions of the Present Road Covered With Stone.—After bringing the present surface to

the proper cross-section, as previously directed, it is to be covered with a layer of broken trap rock varying in size from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches, so as to roll to a thickness of not less than 3 inches, the broken stone to be applied before rolling the loosened stone of the old surface, unless the process of shaping up the old roadbed shall necessitate a thickness of more than 4 inches of loosened stone, in which case it shall be rolled before applying the top layer. The broken stone for the resurfacing is to be spread, rolled, and finished in the manner indicated for spreading the broken stone for macadam construction.

87. Rolling.—The rolling of the different courses of stone shall begin at either edge of the road and work toward the middle. Any special directions as to the manner of rolling which may be given by the Engineer in order to secure the best results shall be strictly followed.

PAVEMENTS

GENERAL CONSIDERATIONS

1. Object of Pavements.—Pavements are constructed for the purpose of improving the facilities for, and reducing the cost of, transportation, and for increasing the safety, speed, and comfort of travel. The duty of a pavement is to furnish an impervious covering that will protect the soil of the natural foundation, and distribute the concentrated weight of the loads more evenly on it, at the same time affording a smooth even surface that will offer the least possible resistance to traction, and over which vehicles may pass with ease and safety.

2. Qualities Essential to Pavements.—A good pavement should be: (1) impervious, in order not to retain water or surface liquids, but to facilitate their discharge into the side gutters; (2) such as to afford a secure foothold for horses, and not to become polished and slippery from use; (3) hard, tough, and durable, so as to resist wear and disintegration; (4) adapted to the grade; (5) suited to the traffic; (6) smooth and even, so as to offer the minimum resistance to traction; (7) comparatively noiseless; (8) such as to yield very little dust or mud; (9) easily cleaned; and (10) economical with regard to first cost and maintenance.

It is also desirable that the pavement should be of such material and construction that it can be readily taken up in places and quickly and substantially relaid, in order to give access to water, gas, and sewer pipes.

3. Of What a Pavement Consists.—A pavement consists of two more or less distinct parts; namely, the *wearing surface*, and the *foundation* by which the wearing surface is supported.

The wearing surface may be termed the working portion of the pavement; it is that visible part with which those who travel over it are familiar. It receives and sustains the traffic, and is that part of a pavement by which the traffic is directly affected. The first nine items of the preceding article relate directly to the wearing surface, which must be of such material and so constructed that it will not only be best suited to the traffic but also resist its destructive effect in the best possible manner.

The wearing surface, however, is properly little more than a surface, and is not of itself capable of sustaining the traffic and distributing its weight over a sufficient area of the yielding soil beneath it. Hence, it is necessary that the wearing surface should rest on, and be sustained by, a foundation having sufficient strength to resist deformation and to distribute the concentrated weights of the traffic over a sufficient area of the underlying soil, so that the latter will sustain it without injury. In any pavement, the value and condition of the wearing surface, and, consequently, the value of the pavement, will depend largely on the foundation.

4. Classification of Pavements.—The different kinds of pavements are generally designated by the names of the materials used for their wearing surfaces. Prominent exceptions to this are the macadam and telford broken-stone pavements, which have practically the same wearing surfaces, but differ materially with regard to their foundations.

There are and have been many varieties of pavements, of which the ones most extensively used are: (1) asphalt pavements; (2) brick pavements; (3) stone-block pavements; (4) wooden-block pavements; (5) cobble-stone pavements; and (6) broken-stone pavements. These are named in about the order of their comparative merit, although the comparative merit of different pavements will depend greatly

on the character of the traffic to which they are subjected. When properly constructed and subjected to the character of traffic to which they are adapted, most of these pavements have proved fairly satisfactory.

Each kind named may be taken to represent a class. Under the name of "asphalt pavements" are included not only all kinds of asphalt pavements, properly so called, but also all pavements composed of bituminous products, such as the pavements known as bitulithic, tar-macadam, etc. Under the name of "stone-block pavements" are included all pavements composed of stone shaped to any required form, such as the pavements known as granite-block, Belgian-block, etc. The name "wooden-block pavements" includes all wood pavements; while by "cobblestone pavements" is meant all pavements composed of natural stone, unshaped and unbroken.

CHOICE OF PAVEMENTS

5. Factors Involved.—The selection of the pavement most suitable to a given roadway will depend greatly on the local circumstances attending each particular case. The suitability of the pavement should be considered with reference to each of the following conditions: (1) adaptability; (2) serviceableness, including safety; (3) durability; and (4) economy. It will be well here to notice each of these conditions separately, although they are more or less dependent on one another. As streets usually run through thickly populated districts, the questions of comfort to the residents, sanitation, and noise must also be considered.

6. Adaptability.—The pavement on a roadway should be adapted to the class of traffic that will pass over it. The pavement suited to the roadway of a suburban district would not be suited to the roadway of a manufacturing center, and the pavement suitable for a residence street would not be well adapted to the requirements of a street sustaining very heavy traffic. In general, it may be stated that, for important commercial thoroughfares sustaining heavy and constant

traffic, granite-block pavements are suitable; asphalt, brick, and wooden-block pavements are well adapted to the requirements of streets in localities where noise is very undesirable, such as important residence streets and streets devoted to retail trade; while, for pleasure drives and suburban streets having light traffic, broken-stone pavements are suitable.

7. Serviceableness.—The serviceableness of a pavement, or its fitness for use, may be measured by the expense caused to the traffic using it—that is, the fatigue of horses, wear and tear of vehicles, loss of time, etc. It will depend to some extent on the foothold that it affords to horses. The rougher the surface of the pavement, the more secure will be the foothold afforded, while at the same time the greater will be the resistance to traction. Cobblestone pavement affords an excellent foothold, but offers great resistance to traction and causes much wear and tear of vehicles. Asphalt pavement affords a less secure foothold for horses than almost any other kind of pavement, but it also offers less resistance to traction and causes less wear and tear of vehicles. The best measure of these conditions is the expense to the traffic using the pavement. For this purpose, however, no statistics are available. The cost of wear and tear on different pavements has been roughly estimated to be as given in Table I.

TABLE I

COST OF WEAR AND TEAR ON PAVEMENTS

Kind of Pavement	Estimated Cost, in Cents per Mile Traveled
Cobblestone	5.0
Belgian block	4.0
Granite block	3.0
Wood	2.5
First-class broken stone	1.2
Asphalt	1.0

8. Safety.—The comparison of different pavements with regard to safety is commonly based on the foothold they afford to horses. The comparative security of foothold afforded to horses by roadway surfaces of different materials, stated in the order of their safety, is as follows: (1) earth, dry and compact; (2) gravel; (3) broken stone; (4) wood; (5) sandstone and brick; (6) asphalt; and (7) granite block.

Statistics also indicate the following conditions regarding the safety of three very common pavements; namely, asphalt, wood, and granite:

Asphalt and wood are most slippery when merely damp, and safest when perfectly dry; they are also safest when clean. Asphalt requires but little moisture to become very slippery, and it is in its most slippery condition when dry weather comes after rain. Wood requires more rain than asphalt before reaching its most slippery condition, but the slippery condition lasts longer. A small quantity of dirt on asphalt makes it very slippery. Asphalt is usually dry and safe in winter during frost, while wood, retaining moisture, is very slippery. Under snow, however, there is very little difference.

Slipperiness may be prevented on asphalt by sprinkling it with sand, and on wood by sprinkling it with gravel. More or less dirt and dust will, of course, result. The tendency of sand is to wear out the asphalt, while the tendency of gravel is to preserve the wood.

Granite is most slippery when dry, and safest when thoroughly wet; it is also less safe when clean. In damp weather, the granite blocks become greasy and slippery. The blocks always become more or less rounded by the traffic, and, in dry weather, if the granite is of a hard close-grained variety, the surfaces of the blocks become polished and very slippery.

9. Durability.—The durability of a pavement is that property which relates to the length of time that the pavement is able to sustain the traffic satisfactorily—that is, to the length of time that the pavement remains serviceable.

This will not necessarily be as long a time as the pavement remains in use nor as long as the actual durability of the materials composing it. The pavement will remain serviceable so long only as its surface stays in proper condition. The durability of a pavement is best measured by the amount of traffic, estimated as tonnage, that it will sustain before its condition becomes so bad that the current expense to the traffic, in excess of the expense of a perfect pavement, is greater than the interest on the cost of renewal of the pavement.

The durability of a pavement depends to a great extent on the condition in which it is maintained, especially with reference to cleanliness. A covering of dirt about 1 inch in thickness will protect a pavement from abrasion and greatly prolong its life. The covering of dirt, however, is very unsanitary, and otherwise objectionable: in wet weather it produces mud, and in dry weather, dust.

10. Life of Pavements.—The period of durability of a pavement is commonly spoken of as the **life** of the pavement. The life of different pavements under like conditions of traffic and maintenance may be taken as given in Table II.

TABLE II

COMPARATIVE LIFE IN YEARS OF DIFFERENT PAVEMENTS

Kind of Pavement	Minimum	Maximum	Mean
Granite block	12	30	21
Asphalt	10	14	12
Brick	5	15	10
Sandstone block	6	12	9
Wood	3	7	5
Limestone	1	3	2

The figures in this table probably represent fair values of the comparative durability of the different pavements under like conditions, but they do not represent the greatest endurance of the different pavements under the most favorable

conditions. In London, a pavement of Aberdeen granite has lasted for 35 years, and some asphalt pavements on streets having very heavy traffic are 19 years old. It is stated that, in the Netherlands, brick pavements laid over half a century ago are still in a good state of preservation; and in the United States there are brick pavements from 10 to 18 years old that are still in good condition. The life of wooden pavements has been from $5\frac{1}{2}$ to 19 years in London, and in Chicago from 3 to 10 years. In this connection, it is noteworthy that the life of pavements in London under very severe conditions of traffic is generally considerably greater than in large cities of the United States; this is probably due to greater care in their construction and maintenance.

11. Economy.—The actual economy of a pavement relates not only to its first cost, but also to the cost of maintenance, cost of repairs to vehicles, and fatigue of horses, together with the facility for transportation, saving of time, and ease and comfort of travel afforded by its use. The pavement that costs the least is not always, nor even generally, the most economical, nor is the pavement that costs the most always the best. The most economical pavement, in a true sense, is the one that is the most beneficial and profitable in proportion to the cost of construction and maintenance. This will always be the pavement that is best adapted to the location and on which a sufficient amount has been judiciously expended to secure the best results. It will cost more to construct a good pavement than to construct a poor one, but the well-constructed pavement will last much longer, be more cheaply maintained, and afford much greater benefit to those who use it than the poorly constructed pavement.

ECONOMICS OF PAVEMENTS

12. Relative Economy.—The relative economic values of different pavements, whether of the same kind in different conditions, or of different kinds, may be determined with reasonable fairness and sufficient accuracy by comparing the average cost per ton to the traffic on the different pavements for any certain uniform distance. The average cost per ton may be obtained by dividing the total annual cost of the pavement by the total annual tonnage of the traffic on it. The various values and conditions involved in this operation will now be treated separately.

13. Total Annual Cost.—The total annual cost of the pavement is made up of various items of annual expense; it may be estimated by the following formula:

$$a = k + m + c + s + d$$

in which a = total cost;
k = first cost of pavement;
m = cost of maintenance;
c = cost of cleaning and sprinkling;
s = cost of service;
d = damages consequent to the pavement,
all these being accounted as items of *annual* expense.

14. Annual Charge for First Cost.—The first cost should be considered as an investment running for a period of time equal to the life of the pavement and having no value at the end of that period, except that represented by the permanent foundation and old materials. Consequently, the annual charge for first cost will be materially affected by the life of the pavement; its proper value k may be obtained by the formula

$$k = \frac{c_1 - f}{n} + i$$

in which c_1 = total first cost of pavement;
i = annual interest (usually at 4 per cent.) on first cost;
f = final value of foundation and old materials;
n = number of years of satisfactory service, or life of pavement.

When the actual life of the pavement is not known, its probable life may be taken at the mean value given for different pavements in the last column of Table II.

The first cost of a pavement depends greatly on local conditions, and, consequently, varies considerably in different localities. The costs given in Table III represent fairly the costs per square yard of different pavements in various cities of the United States. The mean values given are not in all cases the average of the maximum and minimum values.

TABLE III

FIRST COST OF DIFFERENT PAVEMENTS

Kind of Pavement	Cost, in Dollars, per Square Yard		
	Min.	Max.	Mean
Asphalt (concrete foundation)	1.95	4.50	3.00
Granite block (sand or gravel foundation)	1.50	4.25	2.80
Sandstone block (sand or gravel foundation)	1.30	3.00	2.50
Brick (sand or gravel foundation)	1.00	2.80	1.90
Wood (sand or gravel foundation)	.95	2.00	1.50
Cobblestone (sand or gravel foundation)	.40	1.60	1.00
Separate cost of concrete foundation	.60	1.50	1.00

For convenience, the first cost of all pavements will be taken hereafter as given in the last column of this table. The cost of Belgian-block pavement may be assumed to be the same as that of sandstone block. For stone-block, brick, or wooden pavement on concrete foundation, 90 cents per square yard will be added to the cost of each as given in Table III for sand or gravel foundation.

15. Final Value of Pavements.—If the foundation is of a permanent nature, its final value—that is, its value at the end of the life of the pavement—will generally not vary greatly from its first cost. A final value of 90 cents per square yard will here be used for concrete foundations, while ordinary sand and gravel foundations will be considered to have a final value of 10 cents per square yard. The final value of the surface material of a pavement can be determined with a reasonable degree of accuracy only at the expiration of its service. Here, however, it will be taken as given in Table IV.

TABLE IV

FINAL VALUE OF OLD SURFACE MATERIAL

Kind of Pavement	Estimated Value Cents per Square Yard
Granite block	80
Sandstone block	60
Brick	20
Asphalt	10
Wood	00

EXAMPLE.—A roadway 30 feet wide between curbs is paved with granite blocks on a gravel foundation. What is the annual charge for first cost against a piece of this pavement 10 yards in length, interest being taken as 4 per cent.?

SOLUTION.—A width of 30 ft. is equal to $30 \div 3 = 10$ yd., giving an area of $10 \times 10 = 100$ sq. yd. in the piece of pavement. From Table III, the mean cost of granite-block pavement on a sand or gravel foundation is $2.80 per sq. yd.; as given above, the final values of the foundation and old surface material are 10 and 80 ct., respectively, or a total of 90 ct. per sq. yd.; and from Table II, the mean life of granite-block pavement is 21 yr. Hence, by the formula in Art. **14**, the annual charge against the pavement for first cost will be

$$\frac{100 \times (2.80 - .90)}{21} + 100 \times .04 \times 2.80 = \$20.25. \quad \text{Ans.}$$

16. Annual Cost of Maintenance.—The proper maintenance of a pavement consists in keeping it in practically as good a condition as when first constructed. The total cost

of maintenance includes all outlays for repairs and renewals during the life of the pavement, and the average annual cost will be this total cost divided by the number of years of service. The cost of maintenance depends on the kind of pavement, the quality of the materials used, the manner of

TABLE V

ANNUAL COST OF MAINTENANCE

Kind of Pavement	Annual Cost, Cents per Square Yard
Granite block	2
Sandstone block	3
Brick	5
Asphalt	9
Wood	15

construction, the amount and character of the traffic, and the condition in which the pavement is kept as regards cleanliness. The estimated cost of maintenance should be such as would keep the pavement in perfect condition. The annual cost of maintenance of the different pavements will probably average about as given in Table V. These values will be used here.

TABLE VI

ANNUAL COST FOR CLEANING AND SPRINKLING

Kind of Pavement	Annual Cost, Cents per Square Yard
Asphalt	2
Brick	5
Stone block	10
Wood	12

17. Annual Cost of Cleaning and Sprinkling. The annual cost of cleaning and sprinkling should be the actual or estimated expense for keeping the pavement in

a clean and dustless condition. This cost depends chiefly on the character of the material of which the pavement is composed and on the condition of its surface. The actual cost of cleaning and sprinkling can be easily ascertained for each particular case. For convenience, the costs given in Table VI, which are probably fair average values, will be used hereafter in all computations.

18. Annual Service Cost.—The annual service cost consists of the various items of expense to the traffic resulting from the use of the pavement. Any loss of time or revenue caused by the limitation of speed or load below what would be afforded by a perfect pavement should be included under this head, as should also the reduced life service of horses, and the reduced value of their efficiency, resulting from imperfect or unsuitable pavements. The cost

TABLE VII

ANNUAL SERVICE COST OF PAVEMENTS

Kind of Pavement	Annual Cost, Cents per Square Yard
Asphalt	15
Brick	20
Wood	25
Stone block	40

of wear and tear to the traffic using the pavement should also be included (see Table I). These various items should be estimated for each particular pavement, covering a period of 1 year, and their sum substituted for s in the formula of Art. **13**. The values of the different items depend on the kind of pavement and its condition, and on the amount and character of the traffic. As statistics are not available, the total annual cost for service will here be taken as given in Table VII, in which the values are roughly estimated.

19. Consequent Damages.—Under the head of consequent damages are included all damages resulting from

the use of defective or unsuitable pavements. This involves the consideration of many and diverse circumstances, among which may be named injury to health resulting from unsanitary conditions, aggravation of nervous complaints due to noise, injury to merchandise from dust and mud, reduced rental value of buildings due to rough, dirty, noisy, or unsanitary pavements, etc. Estimates of such damages can necessarily be only roughly approximate, even when made with care. The sum of all such items, as estimated to cover a period of 1 year, will determine the value of the quantity d in the formula of Art. **13.** For convenience, the values given in Table VIII will here be used in all estimates. It is to be distinctly understood, however, that these values are merely very rough approximations.

TABLE VIII

ESTIMATED DAMAGES CONSEQUENT TO PAVEMENT

Kind of Pavement	Annual Damages, Cents per Square Yard
Asphalt	2
Wood	4
Brick	5
Stone block	10

EXAMPLE.—For the pavement considered in the example of Art. **15,** what is the total annual cost resulting from the pavement?

SOLUTION.—As determined in the example referred to, the annual charge for first cost is \$20.25; the annual cost of maintenance is $100 \times .02 = \$2$ (Art. **16**); the annual cost for cleaning and sprinkling is $100 \times .10 = \$10$ (Art. **17**); the annual service cost is $100 \times .40 = \$40$ (Art. **18**); and the annual charge for consequent damages is $100 \times .10 = \$10$ (Art. **19**). Consequently, the total annual cost resulting from these 100 sq. yd. of pavement is

$$20.25 + 2 + 10 + 40 + 10 = \$82.25 \quad \text{Ans.}$$

20. Basis of Comparison.—When the total expense chargeable against any certain piece of pavement has been estimated in the manner just described, for the purpose of comparison with other pavements, the total tonnage of the

traffic over the same piece of pavement for a corresponding length of time must also be estimated, in order to determine the cost per ton to the traffic; for a number of the items of expense chargeable against each pavement will be materially affected by the amount and character of the traffic on it, so that a just comparison of the relative economies of the different pavements will not be given by a comparison of their actual cost. The cost per ton to the traffic forms the best basis of comparison. If the total cost chargeable against the pavement is divided by the total tonnage of the traffic on it for a corresponding length of time, the quotient will be the cost per ton to the traffic for transportation through a distance equal to the length of the piece of pavement chosen. The cost thus obtained will be the cost per ton-mile, per ton-yard, per ton-foot, etc., according to the length of the piece of pavement chosen for the comparison.

The tonnage of the traffic will be practically uniform throughout each block, and, in many cases, throughout several consecutive blocks. The cost of the pavement, however, will be proportional to its length, and, consequently, the tonnage cost will be proportional to the length of pavement estimated. That is, the cost per ton-yard will be three times the cost per ton-foot, etc. As the cost of pavements is generally estimated by the square yard, the ton-yard will be a convenient unit, and will be used here. Consequently, the length of the pavement for which the total annual cost is estimated should, for convenience, be expressed in yards.

This method of comparing the relative economy of pavements involves some error, on account of the fact that the first cost of the pavement, as well as several of the other expenses chargeable to it, will vary directly with its width; while the amount of traffic will not generally be greatly affected by the width of roadway, but will depend on various conditions impossible to express by formula. Moreover, the annual charge for first cost will be materially affected by the life of the pavement; the cost of maintenance will depend largely on the thoroughness of the construction; while both the service cost and the consequent damages will depend

largely on the condition in which the pavement is maintained. It is thus seen that there are many uncertain conditions involved; and anything approaching exactness in the results is not to be expected.

21. Census of the Traffic Tonnage.—The tonnage of the traffic over a pavement can be ascertained only by direct observation. As the amount of traffic is variable, the observations should extend over a sufficient period to obtain good average results, should be continuous through each day for several consecutive days, and should be repeated at different seasons of the year. Such a series of observations is called a **traffic census**. The kind of pavement, state of repair, condition of surface with regard to being clean, dry, damp, wet, or greasy, and also the number and kinds of partial or complete falls of horses should be noted when the observations are taken.

In making the observations, the weight of each vehicle must be roughly estimated. In order that the observer may make an intelligent estimate, the different kinds of vehicles should be classified according to their approximate weights. The proper weight to be assigned to each class of vehicles may be determined by occasionally weighing a typical vehicle with its load. If this is done, the total tonnage estimated by each day's observation will probably not vary greatly from the actual total.

22. Classification of Tonnage.—The following classification has been used in practice in making observations of tonnage:

LESS THAN 1 TON

One-horse carriages, empty or loaded.
One-horse wagons, empty or lightly loaded.
One-horse carts, empty.

BETWEEN 1 AND 3 TONS

One-horse wagons, heavily loaded.
One-horse carts, loaded.
Two-horse wagons, empty or lightly loaded.

MORE THAN 3 TONS

Wagons and trucks drawn by two or more horses and heavily loaded, special note, with estimate of weight, being made of any unusually heavy loads, such as large trucks loaded with stone or iron.

The following weights were assigned to each class of vehicle:

Light-weight vehicles, including load, $\frac{1}{2}$ ton each.
Medium-weight vehicles, including load, 2 tons each.
Heavy-weight vehicles, including load, 4 tons each.

23. Average Daily Tonnage.—If the total number of vehicles observed in each class is multiplied by the weight assigned to that class, the sum of the results will be the total tonnage during the entire period of observation. This sum, divided by the number of days of observation, will give the average daily tonnage on the roadway. If this average is divided by the width of the roadway between curbs, in yards or feet, the quotient will be the daily tonnage per yard or per foot of width. For the purpose of ascertaining the relative economy of different pavements, however, it will be as well to take the tonnage on the full width of roadway, the cost chargeable to the pavement being, of course, estimated for the same width. If the ton-yard is taken as the unit of cost, the traffic tonnage over 1 yard in length of the roadway is what should be observed. This will, of course, be equivalent to the tonnage passing any given point or cross-section of the roadway. If, then, the weight of each class of vehicle is taken as given in the preceding article, the average daily tonnage d_t on the roadway will be given by the formula

$$d_t = \frac{\frac{1}{2} l_1 + 2 m_1 + 4 h_1}{d_o}$$

in which l_1, m_1, and h_1 are the total number of vehicles observed in the light, medium, and heavy class, respectively, and d_o is the total number of days of observation.

EXAMPLE.—During 6 days of continuous observation, the number of vehicles passing over the pavement described in the example of

Art. **15** was found to be 3,186, classified as follows: 1,448 light, 1,258 medium, and 480 heavy. What is the average daily tonnage?

SOLUTION.—By the formula in this article, the average daily tonnage is

$$\frac{\frac{1}{2} \times 1{,}448 + 2 \times 1{,}258 + 4 \times 480}{6} = 860 \text{ T.} \quad \text{Ans.}$$

24. Statistics of Observed Tonnage.—The general average of the daily tonnage for certain cities of the United States in which observations have been made was found to be 77 tons per foot of width. The average for different cities varied from 151 tons in New York City to 30 tons in Buffalo. For different streets, the tonnage varied from 273 tons per foot of width on Broadway, New York City, to 7 tons on a granite-paved street in St. Louis. For all cities observed, the average weight of vehicles was found to be 1.15 tons. In London, on certain streets that are paved with asphalt and on others that are paved with wood, the daily traffic tonnage exceeds 400 tons per foot of width; while in Liverpool, granite-block pavements sustain a daily traffic tonnage of from 400 to 500 tons per foot of width.

25. Cost per Ton-Yard.—From what has been given in the preceding article, the following formula may be derived for the value of t_y, the average cost to the traffic per ton-yard:

$$t_y = \frac{a}{365\, d_t\, y}$$

in which a = total annual cost chargeable against pavement, as given by formula in Art. **13**;

d_t = average daily traffic tonnage, as given by formula in Art. **23**;

y = length of roadway in yards, on which the cost of pavement is estimated.

The value of a should be expressed in cents; the value of t_y will then be in fractions of a cent.

EXAMPLE.—If the examples given in Arts. **15**, **19**, and **23** relate to the same pavement, what is the average cost per ton-yard?

SOLUTION.—The value of a is \$82.25 = 8,225 ct. (Art. **19**); the value of d_t is 860 T. (Art. **23**); and the value of y is 10 yd. Hence, substituting in the formula of this article,

$$t_y = \frac{8,225}{365 \times 860 \times 10} = .00262 \text{ ct. } \quad \textbf{Ans.}$$

EXAMPLES FOR PRACTICE

NOTE.—In all the following computations, the costs and values relating to pavements will be taken as given in the preceding articles. In the following examples, it will be convenient to estimate the total annual cost for 1 yard in length of roadway.

1. For a roadway 36 feet wide paved with asphalt, a traffic census extending through a period of 4 days gave the following as the total number of vehicles observed in each class: 1,680 light, 484 medium, and 88 heavy vehicles. What was the average cost per ton-yard? Ans. .00345 ct.

2. For a roadway 33 feet wide, paved with brick on a concrete foundation, a traffic census extending through a period of 10 days gave the following as the total number of vehicles observed in each class: 2,040 light, 1,506 medium, and 742 heavy vehicles. What was the average cost per ton-yard? Ans. .00272 ct.

3. For a roadway 30 feet wide, paved with wood on an ordinary sand foundation, a traffic census extending through a period of 8 days gave the following as the total number of vehicles observed in each class: 2,112 light, 1,136 medium, and 488 heavy vehicles. What was the average cost per ton-yard? Ans. .00374 ct.

4. For a roadway 42 feet wide, paved with sandstone blocks on a concrete foundation, a traffic census extending through a period of 6 days gave the following as the total number of vehicles observed in each class: 1,464 light, 1,176 medium, and 564 heavy vehicles. What was the average cost per ton-yard? Ans. .00421 ct.

26. Selecting the Paving Material.—The selection of the paving material depends not only on cost, but also to a certain extent on the grade of the street. The maximum grade on which the different materials may be used is about as follows: asphalt and wood, 4 per cent.; brick, 7 per cent.; stone blocks, 15 per cent. The width of a street, too, influences the selection. For instance, it would not be advisable to place wood on a narrow street lined with high buildings, because, owing to the exclusion of light and air, the pavement would decay rapidly.

PAVING MATERIALS

ESSENTIAL PROPERTIES AND TESTS

27. Materials Employed.—The materials commonly used for the wearing surfaces of pavements are the following: **stone,** in the form of blocks, small boulders, and broken fragments; **wood,** in the form of blocks and plank; **asphalt,** in the two forms known as sheet and block asphalt; and **clay,** in the form of bricks. For the foundations, **hydraulic-cement concrete, bituminous concrete, brick, broken stone, gravel, sand,** and **plank** are employed.

28. Essential Properties of Paving Materials.—The properties most essential to the materials used for the wearing surfaces of pavements are: (1) hardness, or the ability to resist wear by abrasion and attrition; (2) toughness, or the ability to endure hard usage and withstand the destructive effect of blows; (3) the ability to withstand disintegration from the destructive effect of the weather and of the acids produced by decomposing organic matter; (4) imperviousness to water. This last property is closely related to (3). The disintegrating effect of frost on materials is very great, and the less water absorbed by the material, the less will the material be affected by frost; consequently, the non-absorbing property is very essential to a satisfactory paving material.

29. Tests.—As the extent to which the properties mentioned are present in any material is variable, it is necessary, in order to form an opinion of the probable behavior of a given material, to submit specimens of it to experimental tests. It may be well to mention that, as yet, no artificial test has been devised that can definitely determine the most suitable paving material for any street or locality; actual

use for a length of time under the given conditions is the only reliable test.

The present practice of testing materials includes the determination of: (1) the specific gravity; (2) the resistance to crushing; (3) the permeability, or absorptive capacity; (4) the resistance to abrasion; and (5) the resistance to impact.

30. Toughness: Resistance to Crushing.—No satisfactory test for determining the toughness of paving material has been devised. Breaking and crushing tests indicate to some extent the toughness of the material, but are not of great value for this purpose. A quick sharp blow from a light hammer will probably indicate this quality about as well as any ordinary test that can be applied. The blows of the hammer correspond somewhat to the quick blows of the iron-shod hoofs of the horses on the material when in the pavement.

Resistance to crushing, however, is commonly considered to indicate, to some extent, the value of a material for paving purposes. Rough average values of the crushing strength of ordinary materials are given in *Foundations*, Part 1. In practice, the required strength of the materials to be used for a pavement is stated in the specifications.

31. Absorptive Capacity and Specific Gravity. The durability of materials is much affected by their capacity to absorb water. The water absorbed tends to disintegrate the material by the expansion produced by freezing; the more water the material contains, the greater will be the disintegration. The absorptive capacity of a material depends largely on density: a dense material absorbs less water than a porous one. Other conditions being equal, the less the absorption the better the material. Materials that have begun to decompose absorb much more water than those that are perfectly sound.

32. Resistance to abrasion is ascertained either by grinding, in a suitable apparatus, weighed specimens in both a wet and a dry condition, and reweighing and calculating

the loss, or by tumbling the samples about in a cast-iron barrel, called a **rattler**, either alone or with pieces of iron. The test with the iron is considered to approximate more closely than any other the action of traffic. For the purpose of comparison, pieces of a material of a known quality are often included with the samples to be tested. The test is conducted in the manner described in *Highways*.

The rattler test, though of considerable value, is not entirely satisfactory, because the material that is worn from the specimen represents the combined effect of impact and abrasion on all sides, while in the pavement, the material is supported and but one surface is subject to wear; the rattler test therefore must not be relied on entirely to decide between two otherwise good samples.

The drop, or impact, test is made as described in *Highways*.

GENERAL DESCRIPTION OF MATERIALS

STONE AND WOOD

33. Stone.—The stone used for pavements is generally obtained from the granitic, sandstone, and limestone rocks. Among the varieties of granite, those containing a large percentage of feldspar or mica are unsuitable for paving. The feldspar rapidly decays in consequence of the action of the air and water. The micaceous stones are too easily laminated. The limestones, when used for paving, wear unevenly, and under the action of frost are speedily split and broken.

34. Wood.—Many different kinds of wood have been employed for paving. In general, it may be stated that the hard woods have not been found to be the most suitable for pavements; the close-grained, pitchy, soft woods wear longer and afford a better foothold for horses. In the United States, cedar and cypress are the varieties that have been most extensively used, though juniper, tamarack, and yellow pine have been employed to some extent. Of recent years, mesquite, a very hard wood that grows in abundance

in Texas and Mexico, has been used with satisfactory results. Two varieties of Australian hardwood have also been tried. In Europe, most varieties of the pine species, and also oak, deal, ash, and elm have been tried for paving; Memel and Dantzic fir appear to be generally preferred. Whatever variety of wood is used, it should be of uniform quality, close-grained, perfectly sound, and free from knots, sap, and all indications of incipient decay.

ASPHALT

35. General Description.—The word **asphalt** is the English for the Latin word *asphaltum*, the technical term used to distinguish the solid form of *bitumen*, either in a state of purity or combined with other matter. **Bitumen** is a complex hydrocarbon, the origin of which is unknown; it is considered to be the ultimate product of the decomposition of vegetable and animal matter under conditions that produced: (1) *naphtha;* (2) *petroleum;* (3) *maltha*, or the soft form of bitumen; and (4) *asphaltum*. These substances merge into one another by insensible degrees, and it is impossible to determine at what point in the process the dividing line between the liquid and solid forms is to be drawn.

36. Sources of Supply.—Deposits of asphalt occur in a number of widely separated localities, and are particularly abundant in the tropical regions of America. The best known sources are the island of Trinidad, in the West Indies, and the state of Bermudez, Venezuela. Asphalt occurs also in Cuba, Peru, and Mexico, as well as in various parts of Europe and the United States. In the two first-named localities, it is usually found in the form of large deposits called "lakes." At Trinidad, two classes of asphalt are procured: the variety obtained from the lake, or the main deposit, is called **lake asphalt;** that obtained outside of the lake is called **land asphalt,** and is harder than the lake variety. There has been much discussion and investigation as to the relative merits of these two asphalts for paving purposes, but no definite conclusion has yet been reached.

Deposits of almost pure asphalt are found at several places in the United States; the products of these deposits are described by particular names, as *gilsonite*, *uintahite*, *wurtzilite*, etc.

37. Composition and General Properties.—The products of the different asphalt deposits are not uniform, either in physical properties or in chemical composition. The average composition of bitumen is as follows: carbon, 85 per cent.; hydrogen, 12 per cent.; oxygen, nitrogen, and sulphur, 3 per cent.; total, 100 per cent.

38. Asphalt is decomposed by the action of solvents into three complex substances; namely, **petrolene**, which is a yellow oily substance; **asphaltene**, which is a black, hard, brittle substance; and **retine**, which is a yellow resinous substance. These substances are not always present in the same proportion. A large amount of petrolene causes the asphalt to melt at a low temperature; while a large amount of asphaltene causes it to be brittle and wanting in plasticity and cementing power. What effect retine has is not definitely known.

39. Pure asphalt is of a deep black color, with a reddish-brown tinge. It resembles coal, but possesses a peculiar aromatic odor, which, though scarcely perceptible at ordinary temperatures, is very strong at the boiling point. It burns readily with a heavy thick smoke. At a temperature of 60° F., its specific gravity is about 1.03, depending on the impurities mixed with it. Its density is less than that of water. Asphalt is insoluble in water and alcohol, but may be dissolved in naphtha, benzol, carbon bisulphide, alkalies, and alkaline carbonates. Its consistency at different temperatures is as follows:

Degrees F.	Consistency
Under 50	Solid and brittle
50 to 70	Soft and plastic
70 to 90	Pasty
90 to 120	Glutinous
Above 120	Liquid

40. Refining the Asphalt.—Asphalt is rarely found in a pure state; it usually contains water and various mineral and organic impurities, and while in this condition is generally termed **crude asphalt,** or **asphaltum.**

It is partly or entirely freed of these impurities by heating it in a suitable vessel to a temperature between 300° and 400° F. The water is driven off, and the impurities settle to the bottom or rise to the surface in the form of a scum; the liquid asphalt is drawn off, and is then known as **refined asphalt.** The quantity of pure bitumen in the refined product varies considerably, ranging from about 56 per cent. in the Trinidad to about 95 in the Bermudez, the difference being due to the amount of finely divided matter that does not separate in the refining process.

41. Rock Asphalt.—Asphalt is also found incorporated in the limestone and sandstone strata and in beds of shale, sand, and shells. This class of asphalt is generally called **rock asphalt,** and is known as either **bituminous limestone** or **bituminous sandstone,** according to the rock formation in which it occurs. The amount of bitumen contained in rock asphalt varies from a trace to about 70 per cent.

42. Bituminous sandstones form extensive deposits in both Europe and America. Very large deposits exist in California, and are worked for the production of almost pure bitumen, which is separated from the sand by macerating with water; the liquid asphalt thus produced is hardened by a process of distillation. In the Indian Territory, Kentucky, and Texas are found large deposits of bituminous sandstone, which contains a low percentage of bitumen and is employed as a paving material in its natural state.

43. Bituminous limestones are composed of carbonate of lime impregnated with from 7 to 12 per cent. of bitumen. They form extensive deposits in Europe. Only two deposits are known to exist in the United States, one being in Utah and the other in Texas. Bituminous limestone is the variety most extensively employed in Europe for street paving, under the name **asphalte.** It is used in its natural

condition, being first reduced to powder, then heated and spread while hot on the foundation, tamped, and rolled until compacted.

44. Maltha is the name given to semifluid asphalt, or viscous bitumen. In many localities it is found exuding from beds of shale, sand, etc.; it is also produced from the bituminous sandstones by macerating them with water; its use in paving is for the manufacture of paving cement.

45. Quality of Asphalt.—Asphalt employed for paving should not contain much foreign matter, such as water, earthy impurities, or volatile oil. It should not lose weight when heated for several hours to a temperature of 250° F., and at a temperature of about 60° F. it should be viscous, not brittle or fluid. It should be capable of being drawn out into fine threads, and should not be affected by water or dilute ammonia.

46. Asphalt Cement.—Many of the refined asphalts are too brittle for use. To remedy this defect, the asphalt is mixed with a softening agent called the **flux**. The resulting mixture is called **asphalt cement** or **asphaltic cement.** The agents most extensively employed for a flux are maltha and **residuum oil,** the latter of which is obtained by the distillation of petroleum.

The amount of flux necessary to produce the requisite consistency varies with the nature of the asphalt as well as with the quality of the flux, ranging from 5 to 20 per cent. The asphalt is liquefied by heating it to a temperature of about 300° F.; the flux is then added, and the mixture agitated by mechanical stirrers or an air blast. To ascertain when the proper consistency has been reached, samples of the mixture are tested at frequent intervals by a weighted needle applied by either one or two different machines, named, respectively, **Bowen's** and **Dow's** after their inventors.

Bowen's apparatus consists of a steel needle attached to the free end of a lever, which is supported by a thread wound around a spindle. The spindle has an index that moves over

a dial divided into 360°, and by its revolution measures the vertical movement of the lever. The distance the needle penetrates into the sample is shown on the dial, and the figures so shown are termed **degrees of penetration.** The penetration representing a suitable cement is considered to be from 75 to 100 degrees in 1 second of time at a temperature of 77° F.

Dow's apparatus consists of a No. 2 sewing needle, which is inserted in the end of a rod that is supported in a suitable frame and is so arranged as to allow the needle to slide perpendicularly without friction; the needle is weighted with 50 or 100 grams as desired. The rod is provided with suitable mechanism to operate an index revolving on a dial graduated to measure $\frac{1}{100}$ centimeter. To make a penetration test, the sample is brought to a temperature of 77° and placed under the weighted needle, which is allowed to bear on the sample for a certain time (as 5 seconds), at the end of which the reading on the dial is noted. The amount of penetration for a suitable cement with this machine is considered to range from 3.5 to 4.5 millimeters.

In the absence of a needle machine, the viscosity may be determined by chewing a small piece; if it chews easily, without adhering to the teeth, it may be considered to have about the proper consistency.

47. Artificial asphalt is produced from the residue of coal tar and petroleum. It is considered inferior to the natural product, and varies greatly with the quality of the materials and the temperature at which it has been produced. As a rule, the artificial is more brittle than the natural asphalt; to remedy this defect, sulphur is added. A paving material known as **asphaltina** is so produced.

48. Coal Tar.—The tar or pitch resulting from the distillation of bituminous coal in the manufacture of coal gas resembles natural bitumen so closely in external appearance that it was at one time thought to be equally valuable for paving purposes; it is also called **paving pitch.** Attempts to use it as a cementing material for street

pavements have generally resulted in failure. It is, however, being used extensively in the manufacture of a patented pavement known as **Warren's bitulithic pavement.** As a filler for the joints in stone, block, and brick pavements it is in great demand. The grade known to the trade as No. 4 is used for granite-block, and that known as No. 6 for brick pavements.

A paving cement that is also much used for joint filling is composed of creosote oil and the residuum obtained from the direct distillation of coal tar. The proportions commonly used are 1 gallon of oil to about 45 pounds of residuum, though they vary considerably. The ingredients are melted together in suitable iron boilers, and are used in a boiling state. Asphalt is sometimes used and also coal tar, as well as a mixture of asphalt and coal tar. The names **bituminous cement** and **asphaltic cement** are applied quite generally and indiscriminately to such mixtures, however, regardless of whether they contain asphalt or not.

BRICK

49. Paving brick is manufactured from clay in the manner described in *Stone and Brick*. Brick suitable for paving must possess the following qualities:

1. *Vitrification*, by which the brick is made practically indestructible by the action of the weather. This quality is imparted to the brick in the process of burning. The term vitrification, as applied to paving brick, signifies that the clay under intense heat has been fused into one mass. The indications of complete fusion are the conchoidal fracture and the absence of pores; hence, porosity cannot exist in a thoroughly vitrified brick. The measure for the degree of vitrification is the absorption test.

2. *Toughness*, which enables the brick to resist friction and blows without undue wear.

3. *Uniformity of structure*, which prevents the failure of the brick in spots. This quality is affected by both the process of manufacture and the burning.

The quality of toughness depends on three conditions; namely, (1) the natural quality of the clay; (2) the burning, which, if improperly managed, may destroy this quality entirely; (3) the cooling or annealing process, which, if conducted too rapidly, renders the brick brittle.

50. Bricks suitable for paving should not contain more than 1 per cent. of lime, and should be burned specially for the purpose. When tested on their flat sides, they should offer a resistance to crushing of not less than 8,000 pounds per square inch. They should not absorb more than 5 per cent. of their weight of water, and should be so tough that, when struck a quick blow on the edge with a 4-pound hammer, the edge will not spall or chip. The bricks should be of uniform size, straight, square on edges, and free from fire-cracks or checks. When broken, the fracture should appear smooth and the texture uniform, and when struck together, the pieces should have a firm, metallic ring.

SAND AND CONCRETE

51. Sand.—The sand used for paving purposes should be clean and sharp, and preferably silicious. It should be free from loam and clay, and it should be sharp—that is, the grains should be angular in form, and not rounded.

52. Concrete for the foundations of pavements should be composed of materials of good quality, dense and homogeneous. The voids of the aggregate should be thoroughly filled with the mortar of the matrix, and the proportions of the latter should be such that the voids in the sand will be completely filled by the cement paste. The entire mass should be thoroughly mixed before the addition of water, of which just enough should be used to give the cement the proper consistency; the water should be added in small quantities, and the concrete briskly and thoroughly mixed. The ingredients for hydraulic-cement concrete that should be used for pavement foundations are given in Table IX.

The concrete should be deposited in layers not exceeding 6 inches in thickness, and thoroughly but lightly tamped

until a thin film of moisture appears on the surface. When there are two layers, the surface of the first layer should be moistened before spreading the second.

TABLE IX

INGREDIENTS FOR HYDRAULIC-CEMENT CONCRETE

	Ingredients	Number of Parts by Measure
I	Natural cement	1
	Sand	2
	Broken stone	3
II	Portland cement	1
	Sand	3
	Broken stone	7
III	Portland cement	1
	Sand	$2\frac{1}{2}$
	Gravel	3
	Broken stone	5

53. Bituminous Concrete.—A concrete in which the matrix consists of asphalt cement or coal tar is called **bituminous concrete.** It is prepared in either of two ways:

1. The aggregate is spread over the roadbed and compacted by rolling, and the cement, liquefied by heating, is poured over it until the voids are filled.

2. The aggregate is passed through revolving heaters until it is heated to a temperature of about 250° F.; it is then placed in a mixing machine, the liquid cement is added and the mass mixed until each piece of the aggregate is coated with the cement. The mixture is then hauled to the work, spread, rammed, and rolled with hot rollers.

CONSTRUCTION OF PAVEMENTS

STONE PAVEMENTS

54. Cobblestone Pavement.—A cobblestone pavement consists of cobblestones of nearly uniform size embedded in sand. The roadway is excavated to the required depth and form, and on this foundation is spread a layer of clean sand or fine gravel not less than 10 inches in thickness. In the bed of sand or gravel are set small round boulders or field stone; they are set on their small ends, with their greatest dimensions vertical. The stones are generally

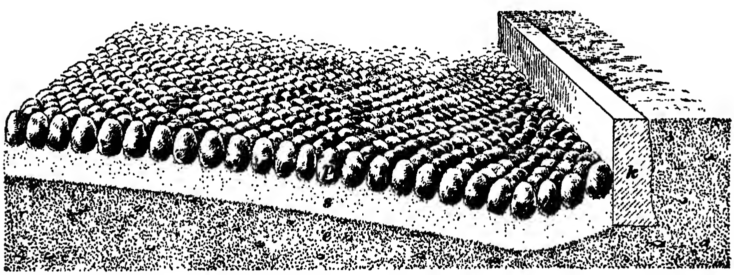


FIG. 1

from 4 to 8 inches in horizontal dimensions, the small stones being placed in the center and the large ones on the sides of the roadway. After the stones are set, they are rammed with a heavy ram until they have settled to a firm and solid bearing in the bed. After the pavement is thoroughly rammed, a layer of sand or fine gravel about 2 inches in thickness is spread over it.

A portion of a cobblestone pavement is shown in perspective in Fig. 1: *p* is the pavement of cobblestone, *s* is the bed of sand or gravel; *e*, the natural earth foundation; and *k*, the curb.

55. Belgian-Block Pavement.—The Belgian-block form of pavement superseded the cobblestone, and, as a natural result, its construction is similar. It was first used in Belgium, whence its name. A sand foundation is prepared much the same as for cobblestone, though it is generally only about 6 inches in depth. The stones are cubical blocks of trap or similar rock, generally from 5 to 7 inches in horizontal dimensions, and from 6 to 7 inches in depth.

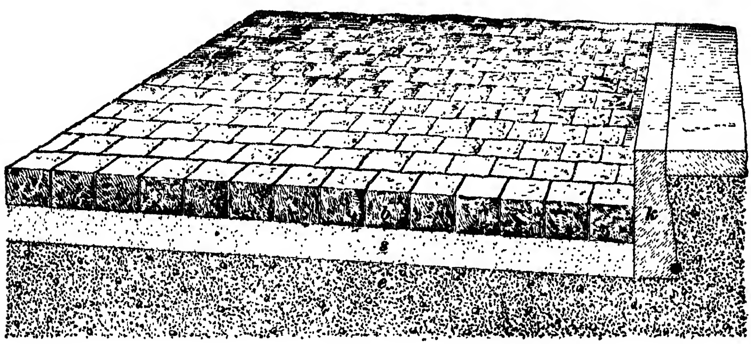


Fig. 2

They are laid in parallel courses perpendicular to the axis of the street. After ramming, the surface of the pavement is covered with clean sand, which is swept into the joints.

A portion of a Belgian-block pavement is shown in perspective in Fig. 2: *b* is the pavement of Belgian block, *s* is the bed of sand or gravel; *e*, the natural earth foundation; and *k*, the curb.

56. Granite-Block Pavement.—Neither cobblestone nor Belgian-block pavements are constructed now on any extensive scale, both having been superseded by the rectangular granite-block pavement, which has proved to be the most enduring and economical pavement for roadways subjected to constant and heavy traffic.

57. The **foundation** for granite-block pavement should be firm and unyielding, hydraulic-cement concrete being the best material for this purpose. The concrete foundation, or **base,** should be from 4 to 9 inches in thickness, according

to the nature of the traffic; a thickness of 6 inches will sustain a very heavy traffic. The foundation should be well laid and thoroughly tamped, and should be allowed sufficient time to set thoroughly and dry before the paving blocks are laid. The surface of the concrete foundation should be parallel to the surface of the finished roadway.

58. Cushion Coat.—A cushion coat of suitable material should be spread on the foundation to receive the paving blocks. The material for the cushion coat should be incompressible, and of such a nature as to adjust itself easily to the irregularities of the paving blocks. For this purpose, fine, clean, dry sand is an excellent material; it must be perfectly dry and free from pebbles. It is a well-established principle that moisture must not be present in the foundation, as frost will have a destructive effect on it. The layer of sand should be from $\frac{3}{4}$ to 1 inch in thickness. A better cushion coat is afforded by a layer of asphaltic cement $\frac{1}{2}$ inch in thickness; this is probably the best possible cushion coat for granite-block pavements.

59. Size and Form of Blocks.—The paving blocks should be rectangular in form, of uniform depth, and of nearly uniform width. A depth of 7 inches is generally considered suitable. Their width should be from 3 to $3\frac{1}{2}$ inches, or, say, such that four blocks placed side by side will make a total width of 14 inches. The lengths of the blocks should vary from about 9 to 12 inches. The blocks should be perfectly rectangular; those that are wedge-shaped ought not to be allowed in the pavement; but should any that are slightly wedge-shaped be permitted, they should be set with their widest edge downwards.

60. Laying the Blocks.—The blocks should be laid in parallel courses; those of the roadway should be laid with their greatest dimensions perpendicular to the axis of the street, while at each outer edge two or three rows of blocks should be set parallel to the curb to form the gutter. The blocks of each course should all be of the same width, and their lengths should be so arranged as to break joints with

the adjacent courses. The block should be laid singly, stone to stone, with the least possible width of joints, the courses being begun at the gutters and laid toward the middle.

At the intersection of cross or connecting streets, the blocks must be laid at right angles to the direction of the traffic; otherwise, ruts will be speedily formed. The most approved method of laying rectangular blocks of stone, wood, brick, or asphalt at street intersections is shown in Fig. 3.

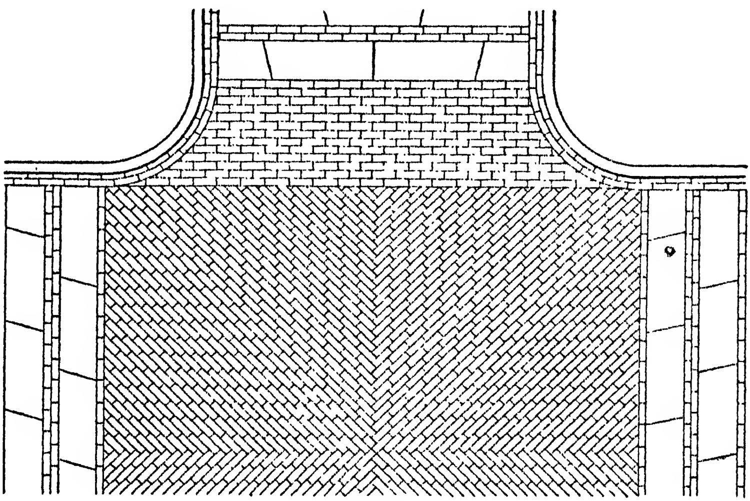


Fig. 3

For the purpose of affording a good foothold, the stone blocks on inclines exceeding 6 per cent. are canted slightly, so that the surface forms a series of steps, against which the horses' feet may rest, or else wide joints with slabs of slate between the stones are used.

61. Ramming.—After being set, the blocks should be thoroughly settled into the sand cushion by ramming them with a ram weighing not less than 50 pounds and having a bottom diameter of not less than 3 inches. Stones that sink below the general level should be taken up and the sand bedding increased sufficiently to bring them to the required height.

The process of ramming should never approach nearer than about 25 feet to the edge of the pavement that is being laid.

62. Joint Filling.—The joint filling should be an impervious material. Sand and gravel do not make an impervious filling, and, consequently, are not suitable for the purpose. A grout composed of lime or cement mortar is not sufficiently elastic, and will become loosened and disintegrated from the vibrations produced by the traffic. The best joint filling is a bituminous concrete composed of paving cement (Art. 53) and gravel. In applying this filling, the joints should be first filled with gravel to a depth of about 2 inches; then the hot pitch should be poured in,

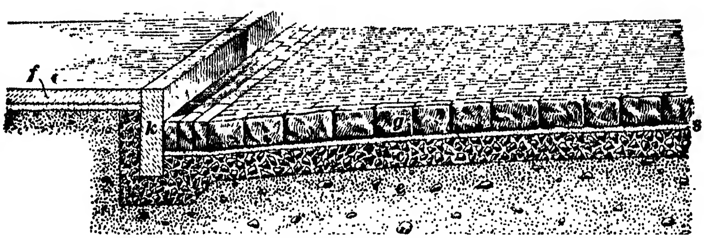


FIG. 4

filling the joints to the depth of about 1 inch above the gravel; then the gravel and pitch should be added alternately until the joints are filled to within ½ inch of the top; the remainder should then be completely filled with pitch, over which fine gravel should be sprinkled. The joint thus formed is impervious to moisture; it adds considerably to the strength of the pavement and makes it less noisy.

In Fig. 4 is shown a perspective view of part of a roadway paved with granite blocks on a concrete foundation: *e* is the natural earth foundation; *c*, the concrete base; *s*, the cushion coat; and *g*, the course of granite blocks. The curb *k* should generally be about 5 inches wide and 18 inches deep; *f* is the sidewalk flagging.

63. Sandstone-Block Pavements.—The best pavements of sandstone blocks are very similar to granite-block

pavements. The blocks are somewhat wider, being generally about 4 inches in width, and the cushion of sand is deeper, being sometimes 3 inches in depth. The concrete foundation and bituminous joint filling are substantially the same as for granite-block pavements.

In second-class sandstone-block pavements, the blocks are more or less irregular in form, and the concrete foundation is omitted. The blocks are laid on a foundation of sand varying from 10 to 18 inches in depth, according to the character of the subsoil. The joints are filled with sand.

64. Broken-Stone Pavement; Macadam.—Macadam's system of broken-stone pavement is generally found very satisfactory for roadways in suburban districts. The construction of broken-stone roads is treated in *Highways*, and but little will be added here to what is there said.

The following important conditions are essential to the construction of a satisfactory broken-stone pavement:

1. The thorough drainage of the subsoil, artificial drains being constructed when necessary.

2. The removal of all vegetable and perishable matter from the roadbed foundation.

3. The excavation of the natural soil to such a depth as may be required by the thickness of the proposed covering. If necessary to excavate deeper than this, in order to remove such material as is liable to decay, the deficit should be filled with gravel, sand, hard pan, or the best similar material obtainable in the locality.

4. The thorough compacting, by rolling, of the roadbed thus formed, before the application of the covering material.

5. The spreading of a layer of gravel on the roadbed before placing the broken stone, when the natural foundation is of the nature of clay.

6. The use of the best broken stone that is obtainable in the locality, and, in general, the use of fragments of different sizes and different degrees of hardness.

7. The exclusion of all clay and loam from the broken-stone covering material, and the use of a sufficient quantity

of clean sand, gravel, or stone dust, and small fragments to completely fill the voids.

8. The compacting of the broken-stone covering, by rolling with a heavy roller, until it is thoroughly consolidated and its surface is impervious to water.

WOODEN PAVEMENTS

65. Different Systems.—Many methods of constructing wooden pavements have been tried, and a number of systems have been patented. The different systems vary with regard to the form of blocks, of which a great variety of forms have been used. In several systems, the blocks are treated with chemicals. By far the greater number of these systems have proved unsatisfactory, and at the present time it is quite generally accepted that the best as well as the simplest form of wood pavement consists of rectangular or cylindrical blocks set on a solid foundation, with the fibers vertical and the joints filled with an impervious cement.

66. Foundation.—A solid unyielding foundation is as essential to a satisfactory wooden pavement as to any other kind; in the United States, however, wooden pavements have very commonly been constructed with insufficient and unsuitable foundations. In most cases, the blocks have been set either in a layer of sand spread on the natural earth foundation or on plank laid on the sand. Such foundations do not sufficiently protect the subsoil, but allow the water to penetrate until the soil becomes saturated and yielding. In this condition, it cannot furnish a firm and solid support to the paving blocks, but will allow them to settle unevenly under the traffic, causing the surface of the pavement to become very rough and uneven. This is the most common defect of wooden pavements, and in nearly all cases is the cause of the rough surface for which wood pavements are so generally condemned.

A solid, unyielding, and impervious foundation that will not only distribute the weight of the concentrated loads over a sufficient area of the natural foundation, but will also

protect the foundation from becoming saturated and unstable, is absolutely essential to the stability and permanence of any pavement. Hydraulic-cement concrete forms the best foundation for this purpose. The construction of the foundation is essentially the same as for granite-block pavements. As wooden pavements are not adapted to as heavy traffic as granite-block pavements, however, the foundations for the former need not generally be of as great depth: a layer of concrete 4 inches in thickness will in many cases be sufficient for the foundation of wooden pavements.

67. A foundation similar to that used for telford pavements has been employed for wooden-block pavements with quite satisfactory results, in cases where the subsoil is of a clayey nature, with occasional soft places. This foundation consists of two layers of stone and gravel. The first layer is 6 inches in thickness, composed of large stones laid with their largest face on the natural foundation, and thoroughly wedged together with all chinks filled with smaller stones, after the manner of the telford foundation. The entire surface is then covered with a layer of wet gravel and thoroughly compacted by rolling. On this is placed a layer of broken stone 2 inches in thickness, which is also covered with wet gravel and thoroughly compacted by rolling. A thin layer of sand is then spread over this, and the whole is covered with a layer or floor of 1-inch boards to give a smooth surface to the foundation.

68. Cushion Coat.—The cushion coat is composed either of dry sand, hydraulic cement, mortar, or asphaltic cement. Whichever is used, it is spread in a layer $\frac{1}{2}$ inch in thickness over the concrete base; the blocks are then bedded in it. When sand is used, it should be perfectly dry, artificial heat being employed to dry it if necessary.

69. Form and Size of Blocks.—Of the many forms of wooden paving blocks that have been tried, only two forms are now commonly used; namely, the rectangular and the cylindrical. The rectangular blocks are generally required to be 3 inches in width, 6 inches in depth, and about 9 inches

in length. These are the dimensions usually preferred, the lengths being allowed to vary somewhat; lengths of from 6 to 12 inches are sometimes specified, but blocks longer than 9 inches have been found to be liable to split. The blocks should be perfectly rectangular. The cylindrical, or "round," blocks are generally required to be from 4 to 8 inches in diameter and 6 inches in depth (length), the diameter of 4 inches being preferred. Each block should be of uniform cross-section throughout its length, with its ends truly perpendicular to its axis. When placed in position in the pavement, the fibers of all blocks should be vertical. As paving blocks usually decay before they wear out, it is probable that blocks of a less depth than 6 inches could be employed to advantage.

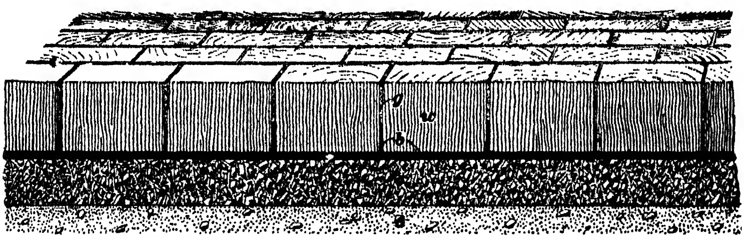


FIG. 5

70. Laying Rectangular Blocks.—Rectangular blocks should be set in parallel courses with their lengths perpendicular to the axis of the street or the direction of the travel. The blocks in each course should break joints with the blocks of the adjoining course by a lap of not less than 2 inches. Adjacent to each curb, about three courses of blocks should be laid parallel to the curb to form the gutter; it is a good plan to leave out the course adjoining the curb until expansion has ceased, filling the unpaved space with sand. At street intersections the courses should be laid diagonally.

In Fig. 5 is shown part of a street pavement of rectangular wooden blocks on a concrete base: *e* is the natural earth foundation; *c*, the concrete base; *w*, the wooden blocks; *b*, the bituminous or asphaltic-cement cushion coat and joint filling; and *g*, the joint filling of hydraulic-cement grout.

The joints should in no case exceed $\frac{3}{8}$ inch, and preferably should not exceed $\frac{1}{4}$ inch in width. Wide joints permit the fibers of the wood to spread, thus rendering it more absorptive and hastening its destruction and decay. The tendency of present practice is toward narrower joints; in some of the wooden pavements constructed in recent years, the blocks have been laid with close joints.

71. Laying Cylindrical Blocks.—Cylindrical, or round, blocks should be set in close contact with one another, extending across the street in parallel rows. Split blocks should be set along the curbs and wherever it is necessary for the edge of the pavement to join on a straight line. No split blocks, however, should be laid in the main part of the pavement.

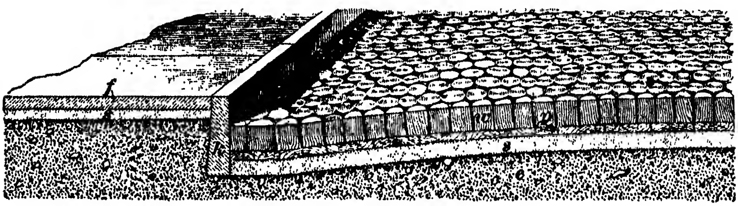


FIG. 6

In Fig. 6 is shown in perspective part of a wooden-block pavement composed of cylindrical blocks on a sand and plank foundation: *e* is the natural earth; *s*, the sand foundation; *p*, the plank covering; *w*, the wooden blocks; *k*, the curb; and *f*, the flagstone of the sidewalk.

72. Ramming.—After the blocks have been laid, they should be rammed with a hand rammer. The amount of ramming required depends to some extent on the kind of foundation employed. Where the blocks rest on a sand and gravel foundation, or on a cushion coat of sand spread over a concrete foundation, the blocks should be rammed, with a rammer weighing not less than 50 pounds, until settled to a solid bearing. All blocks that sink below the general level of the pavement should be taken up and sufficient sand added to raise them to the required height.

Where the blocks rest directly on the concrete foundation, very little ramming is required.

73. Filling the Joints.—Different materials and various methods are employed for filling the joints of wood pavements, and with varying results. It is essential that the joints be filled with a material impervious to water; a filling of sand or gravel is not impervious, and cannot give the best results.

The joints of rectangular-block pavements are sometimes filled with a grout composed of one part of Portland cement and two parts of fine, clean, sharp sand. This is a good filling material, but the best results are obtained by filling the lower 2 or 3 inches with bituminous cement and the remainder with hydraulic-cement grout. The grout forms a good wearing surface, and protects the bitumen from being softened by the direct heat of the sun.

In cylindrical-block pavements, the spaces between the blocks are of considerable size, and it is advantageous to add gravel to the bituminous cement filling. The spaces should first be filled to a depth of about 2 inches with clean well-screened gravel in which the sizes of the pebbles vary from about $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter. Sufficient hot paving cement should then be poured in to fill the joints to a depth of about 2 inches above the gravel; then sufficient gravel added to fill them even with the top of the pavement; then the hot paving cement again poured into the joints until they are completely filled and will absorb no more. After the joints are thus filled, a layer of clean, dry sand should be spread uniformly over the surface of the pavement to a depth of about $\frac{1}{2}$ inch.

74. Expansion of Blocks.—The expansion of wood in a direction perpendicular to its fiber, when exposed to moisture, is very great. The rate and amount of expansion, of course, vary for different woods and different conditions of seasoning; but the average expansion of ordinary pavements composed of untreated blocks will be about $\frac{1}{100}$, or, say, 1 inch in 8 feet. The wood will usually attain its full

amount of expansion in from 12 to 18 months. If no provision is made for expansion, the pressure is likely either to displace the curbs or to distort the pavement itself. In order to avoid this, the joints near the curbs may be left open, or the course adjacent to each curb may be temporarily omitted and the spaces filled with sand; after the expansion has ceased, the pavement should be properly finished by filling the joints left open or setting the courses omitted adjacent to the curbs. Paving blocks impregnated with oil of creosote, however, do not expand or contract to any appreciable extent, and a pavement composed of such blocks may be finished complete at once.

75. Chemical Treatment of Paving Blocks.—The chief cause of the deterioration of well-constructed wooden pavements that are sustained by suitable foundations is the decay due to the action of air and moisture. The wood, being porous, readily absorbs moisture, and the repeated wetting and drying induce decay. For the purpose of preventing or retarding the decay, many different processes of treating the wood with chemicals have been tried. They are described in *Foundations*, Part 1. It will be well to note that the practice of dipping the blocks in coal tar or creosote oil, without previously removing the sap, is injurious rather than advantageous; this confines the moisture and green sap within the blocks, causing fermentation and rapidly destroying the strength of the fibers.

The chemical treatments of paving blocks have very little, if any, effect on the wearing properties of the wood, and the advantages gained appear to be so small as to render them of somewhat doubtful economic value. Where sound, well-seasoned paving blocks are obtainable, and the traffic is of such a nature as to cause them to wear rapidly, little advantage will be derived from chemical treatment. At the present time, the best European practice favors the use of untreated blocks.

ASPHALTUM AND COAL-TAR PAVEMENTS

SHEET ASPHALT: ARTIFICIAL MIXTURE

76. General Considerations.—The asphalt pavements of Europe differ somewhat in their construction from those of America, owing to the difference in the character of the materials used. The former are composed of limestone naturally impregnated with bitumen, while the latter are formed from artificial mixtures of bitumen, sand, and pulverized limestone. The pavements composed of the bituminous limestone become hard, smooth, and slippery under traffic, and are not so satisfactory in frosty latitudes as those constructed from the artificial mixtures; the sand contained in the latter material lessens its slipperiness. The methods of construction described here are those employed in the United States.

77. Foundation.—It is very essential that all pavements of an asphaltic nature be sustained by a solid unyielding foundation, as the asphalt is suitable for a wearing surface only. Two kinds of materials are employed for the foundation; namely, hydraulic-cement concrete and bituminous concrete. Each material has its advantages, but the hydraulic-cement concrete is generally preferred. The concrete foundations for asphalt pavements are usually from 4 to 6 inches in depth, according to the character of the traffic and the nature of the subsoil.

78. Hydraulic Base.—Foundations of hydraulic-cement concrete are very solid and enduring when properly constructed, and are generally preferred. With this material, however, the bond between the foundation and the wearing surface is sometimes so imperfect as to allow the wearing surface to slip on the foundation and roll in waves under the traffic, or crack from extreme changes of temperature. The bond is likely to be very imperfect when the wearing surface is laid before the concrete of the foundation has become set

and thoroughly dry. A foundation composed of hydraulic-cement concrete is sometimes called a **hydraulic base.** It is constructed substantially as described for stone-block pavements.

79. Bituminous Base.—When bituminous concrete is used for the foundation, it unites thoroughly with the wearing surface and forms a strong bond. Although this renders repairs more difficult, it largely prevents the waving and cracking of the asphalt wearing surface. A foundation composed of bituminous concrete is known as a **bituminous base.** In the ordinary construction of this base, a layer of clean, well-screened, broken stone is spread on the prepared roadbed to the proper depth, and thoroughly consolidated by rolling, as in the construction of broken-stone roads, after which a coating of coal tar or bituminous cement is spread on it. The proportions used should be about 1 gallon of cement to each square yard of foundation. Bituminous concrete is less expensive than hydraulic-cement concrete.

80. Binder Course.—In order to effect a more complete bond, an intermediate layer of bituminous concrete is commonly placed between the concrete foundation and the asphalt wearing surface; this is known as the **binder course.** It is composed of clean broken stone of small size mixed with bituminous paving cement. The stones should vary in size from $\frac{1}{2}$ inch in smallest to 1 inch in greatest dimension, and should be thoroughly screened. The stones, which are heated to a temperature of from 230° to 300° F., should be mixed with the paving cement in the proportion of from $\frac{3}{4}$ to 1 gallon of cement to 1 cubic foot of stone. This mixture should be spread, while hot, on the base course to such a depth as will consolidate to a thickness of about $1\frac{1}{2}$ inches; it should then be rammed and rolled, before it loses its plastic condition, until thoroughly compacted. The binder course is substantially the same for both a hydraulic and a bituminous base.

81. Asphalt Paving Material.—When the asphalt paving cement has been prepared as described in Art. **46,**

sand and pulverized limestone are added in the proper proportions, in order to afford a suitable material for the wearing surface of the pavement. For the proportions of the materials, two general formulas are used, which give nearly the same results. They are given in Table X.

TABLE X

INGREDIENTS FOR ASPHALT PAVING MATERIALS

	Ingredients	Proportions Per Cent.
I	Asphaltic cement	12 to 15
	Sand	83 to 70
	Pulverized carbonate of lime	5 to 15
II	Asphaltic cement	13 to 16
	Sand	63 to 58
	Stone dust	28 to 23
	Pulverized carbonate of lime	3 to 5

82. In order to obtain a satisfactory and homogeneous wearing surface for the pavement, the proportions of the different materials must necessarily be varied, according to the character of the materials used, the traffic on the street and the climate. The proportion of asphaltic cement, as well as of carbonate of lime, depends on the quality of the sand. When suitable sand can be obtained, the carbonate of lime may be reduced or even omitted entirely. In any case, the sand must be clean and free from clay.

The asphaltic cement and the sand should be heated separately to a temperature of about 400° F. The proper amount of pulverized carbonate of lime, while cool, should be mixed with the hot sand. This compound should then be mixed with the asphaltic cement at the required temperature and in the right proportions. In order that the materials may be properly mixed, a special apparatus suited to the purpose should be used. The asphalt paving mixture is laid on the foundation or binder course, sometimes in one and

sometimes in two coats. When two coats are laid, the first coat should contain from 2 to 4 per cent. more asphaltic cement than given in Table X.

83. Laying the Asphalt: Two Coats.—The first coat of asphalt is called the **cushion coat**, and the second the **surface coat**. The cushion coat should be laid directly on the binder course, or on the concrete foundation when no binder course is used, and should be of such depth as to give a thickness of $\frac{1}{2}$ inch when consolidated by rolling. The materials for the surface coat, which is laid on the cushion coat, should be delivered on the pavement in carts, at a temperature of about 250° F.; when the temperature of the air is below 50°, each cart should be equipped with a suitable heating apparatus that will prevent the paving material from cooling below the proper temperature.

The material of the surface coat should be carefully spread on the cushion coat to such a depth as will give a uniform surface and a thickness of 2 inches after being consolidated; hot iron rakes should be used for this purpose. The material should first be moderately compressed by hand rollers; a small amount of hydraulic cement should then be spread lightly over it, after which it should be thoroughly compacted by continued rolling with a heavy steam roller for not less than 5 hours for each 1,000 square yards of surface.

84. Laying the Asphalt: One Coat.—When the pavement is given only one coat of asphaltic material, it is laid in much the same manner as just described for the surface coat. The material should be delivered in carts, at a temperature not below 250° nor above 310° F.; while in the carts, it should be protected with canvas covers when the temperature of the air is below 50° F. It should be spread on the foundation to such depth as will give a uniform surface and a thickness of $2\frac{1}{2}$ inches after being consolidated. The material should first be moderately compressed by hand rollers, and a small amount of hydraulic cement should be spread lightly over it, the same as described for the surface coat, after which it should be thoroughly compacted by

rolling with a steam roller weighing not less than 5 tons, followed by a second roller weighing not less than 10 tons; the rolling, should be continued for not less than 10 hours for each 1,000 square yards of surface.

Wearing surfaces properly constructed in the manner just described are suitable for very heavy traffic, and are very enduring. It should be noted, however, that thinner wearing surfaces are by no means uncommon. In the lighter construction, the wearing surface is sometimes made 2 inches thick when laid directly on the concrete foundation, and $1\frac{1}{2}$ inches thick when laid on a binder course. A total thickness of 7 inches is very common for asphalt pavements, including the foundation.

A part of a roadway paved with sheet asphalt pavement is shown in perspective in Fig. 7: *e* is the earth foundation;

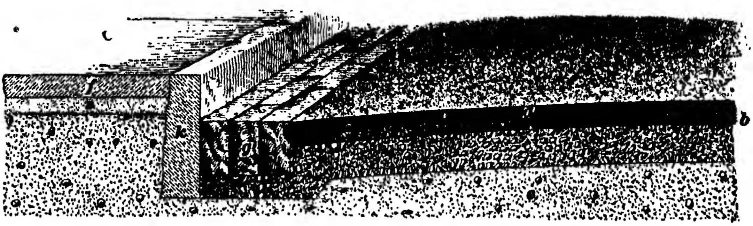


Fig. 7

c, the concrete base; *b*, the binder course; and *a*, the asphalt wearing surface; the gutter is paved with the granite blocks *g*; *k* is the curbstone; *f*, the flagstone of the sidewalk; and *s*, the sand bed on which the latter rests.

85. Gutter Surfaces.—The asphalt paving material described in Arts. **81** and **82** is not wholly impervious to water, and when in continual contact with water tends to rot or disintegrate. With some kinds of asphalt, the disintegration is much more rapid than with others; while with asphalt obtained from certain sources, the paving material is said not to be affected by water.

As pure asphalt is quite impervious to water, the gutter surfaces are sometimes coated with it in order to render them impervious and protect the underlying material. It is

customary to coat a width of about 12 inches adjacent to each curb. The asphalt should be placed on the surface in a hot state, and smoothed with hot smoothing irons, in order to impregnate the surface of the underlying asphaltic material with an excess of asphalt.

In some cases, the gutters are formed of granite blocks, brick, or other suitable material not of an asphaltic nature.

86. Pavement Adjoining Railway Tracks.—When a roadway that is to be paved with asphalt contains street-railway tracks, the asphalt pavement should not be joined directly to the track, but rather to a row of granite paving

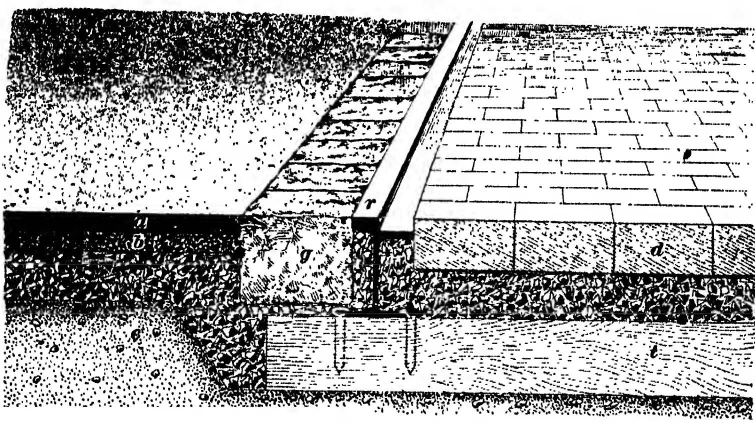


FIG. 8

blocks laid along each side of the track. The foundation for the blocks should extend to the same depth as the bottoms of the cross-ties, but in other respects should be the same as the foundation of the roadway pavement. If this foundation is composed of bituminous concrete, the blocks should be laid directly on it and embedded in it while the bituminous cement is yet in a hot and plastic condition. If the foundation is composed of hydraulic-cement concrete, it should be covered with clean, fine, dry sand to a depth of about 2 inches, and the blocks should be laid on and embedded in the sand.

These paving blocks should be placed in position before the layer of asphalt is placed on the roadway; they should

be laid as headers. The tops of the blocks should be even with the surface of the tread of the rails; the blocks should be laid with close joints, and should be carefully fitted against the heads of the rails. The joints between the blocks should be filled with paving cement and gravel, much as described in Art. 62 for granite-block pavements.

The space between the rails is sometimes paved with brick. In Fig. 8 is shown the part of an asphalt-paved street adjacent to a street-railway track: *a* is the asphalt wearing surface; *b*, the binder course; *c*, the concrete base; *e*, the earth foundation; *g*, the granite-block paving adjoining the rail *r* of the railway track, which rests on the wooden cross-tie *t*; and *d*, the brick pavement between the rails.

NATURAL, OR ROCK, ASPHALT PAVEMENTS

87. Composition.—**Natural**, or **rock**, asphalt, as commonly used for paving purposes in Europe, consists of limestone naturally impregnated with bitumen in such proportion that it may be softened by heat, and again consolidated in the required form when cooled under pressure. This material is also known as **bituminous rock.**

Sandstone rock similarly impregnated with bitumen is found in many places in the United States, and has been used to some extent for paving purposes. The use of natural asphalt for pavements, however, has scarcely passed beyond an experimental stage in this country. It may be stated that the granular nature of the rock renders these pavements less slippery than those constructed of ordinary asphalt, and that they resist disintegration by moisture. It is also claimed that they stand high temperatures and cold, damp atmospheres equally well.

88. Foundation.—The foundation for a natural-asphalt pavement should consist of concrete, substantially the same as described in preceding articles for the artificially prepared asphalt wearing surfaces. A binder course is not employed, however; instead, the natural asphalt, properly prepared,

is laid directly on the concrete foundation, which should preferably be of hydraulic-cement concrete.

89. Preparing the Asphalt.—Natural asphalt is used to form the wearing surface of the pavement. In order to be suitable for this purpose, the natural rock should contain from about 8 to 13 per cent. of bitumen. If it contains more than 13 per cent., it is likely to become soft in warm weather; and if it contains less than 8 per cent., it will not consolidate thoroughly nor have sufficient bond; a range not greater than from 9 to 12 per cent. is preferable. The bitumen should be evenly distributed through the rock, which should be of nearly uniform texture. In order to obtain the proper percentage of bitumen, it is sometimes necessary to mix together rocks obtained from different localities.

The rock is first crushed to fragments of about the size of eggs, and then ground to a fine powder. This powder is heated to the proper temperature (about 300° F.) to soften it to the required consistency.

90. Laying the Asphalt.—The hot material is delivered on the roadway, and by means of hot iron rakes is spread over the concrete foundation to such a depth as will compress to the required thickness. The thickness of the wearing surface after compression should not be less than 2 inches; a compressed thickness of 2 inches requires a depth of about 3 inches for the uncompressed material. Proper precautions should be taken to prevent too much cooling of the asphalt while being transported to the pavement. The asphalt should be laid in dry weather and on a perfectly clean foundation, from which all loose or foreign substances have been removed.

The material, when spread on the foundation, should be vigorously rammed with hot cast-iron rammers of from 6 to 8 inches in diameter, a sufficient number being used to ram the material to a compact condition while still hot. Soon afterwards, the surface should be rolled with a light roller heated by an internal furnace. A small quantity of hydraulic cement should be swept lightly over the surface during the

process of rolling, which should be continued until the asphalt is cooled. The final compression of the pavement is usually left to be effected by the wheels of the traffic.

The method of laying the natural asphalt as here described corresponds to the European rather than the American practice, though it may be considered as fairly representative of the latter.

ASPHALT-BLOCK PAVEMENTS

91. Asphalt Paving Blocks.—Asphalt paving blocks consist of a mixture of asphaltic cement and crushed trap or granite, molded into a form suitable for the purpose. The largest fragments of stone should not exceed $\frac{1}{4}$ inch in greatest dimensions. The asphaltic cement should be prepared as described in Art. **46.** The proportions of the ingredients are about as follows: asphaltic cement, 10 per cent.; crushed stone, 80 per cent.; limestone dust, 10 per cent.

The materials should be heated to a temperature of about 300° F. and mixed while hot in a suitable apparatus. The mixing should be so thorough that the ingredients will be evenly distributed through the entire mass. The mixture is then subjected to heavy pressure in molds somewhat similar to those of a brick machine, after which the blocks thus formed are cooled suddenly by being immersed in cold water. The blocks are commonly 4 inches wide, 3 inches deep, and 12 inches long. For footways, blocks $2\frac{1}{2}$ in. $\times$ 18 in. $\times$ 8 in., called **tiles**, are used. The blocks wear rapidly and are therefore not suitable for streets sustaining heavy traffic; they have given great satisfaction, however, on residence streets where the traffic is light. For such streets, they form a smooth, clean, healthful, and tolerably durable pavement.

92. Foundation.—Asphalt paving blocks are commonly laid on a gravel foundation. The roadbed should be prepared to the proper form and grade, and thoroughly compacted by rolling and ramming. A layer of clean gravel, from which have been screened all pebbles larger than

$1\frac{1}{2}$ inches in greatest dimension, should then be spread on the roadbed to such a depth as will give a thickness of 5 inches when compacted. After this has been thoroughly compacted by rolling and ramming, a layer of fine, clean sand 2 inches in thickness should be spread on it, to serve as a bed for the blocks; the surface of the sand bed should be exactly parallel to the intended surface of the completed roadway.

93. Laying Asphalt Paving Blocks.—The blocks should be laid in parallel courses on the sand bed, with close joints and with their greatest dimensions perpendicular to the axis of the street; the blocks in each course should break joints with the blocks in the adjacent courses by a lap of not less than 4 inches. In laying the blocks, the pavers should stand or kneel on the blocks already laid, so as not to destroy the finished surface of the sand bed. In order to close tightly the lateral joints, each course, when laid, should be driven against the preceding course by means of a heavy

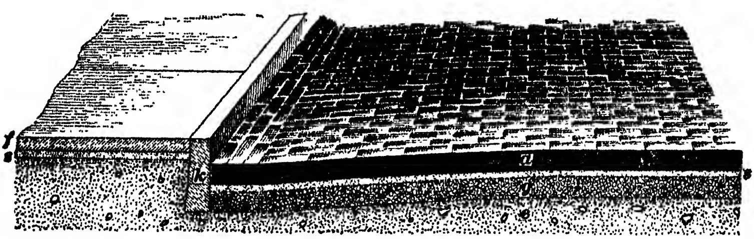


FIG. 9

wooden maul, while the longitudinal joints should be closed by means of a lever operated against the end of each course at the curb. As fast as laid, the pavement should be covered with fine sand that is perfectly clean and dry. The blocks should then be rammed, by striking on an iron plate about 20 inches long, 8 inches wide, and 1 inch thick, with a rammer weighing about 50 pounds; the ramming should continue until the blocks are firmly and solidly bedded and present a uniform surface. All blocks sinking below the general surface of the pavement should be taken up, and the sand bed

increased sufficiently to bring them to the required height. When the pavement has been thoroughly rammed, an additional amount of fine, clean, dry sand should be spread over its surface and swept into the joints.

In such a pavement, the blocks will eventually become cemented together by the heat of the sun and the pressure of the traffic, so as to be practically waterproof. A view of part of a roadway paved with asphalt blocks is shown in Fig. 9: *a* is the asphalt pavement; *s*, the sand cushion; *g*, the gravel base; and *e*, the earth foundation.

BITULITHIC PAVEMENTS

94. A **bitulithic pavement** is composed of broken stone ranging in size from 2 inches to dust, mixed in the necessary proportions to reduce the voids to about 10 per cent., and cemented together by a bituminous cement manufactured either from coal tar, from asphalt, or from a combination of both. The pavement is constructed in much the same manner as an asphalt pavement. The foundation is composed of a 4-inch layer of broken stone compacted by rolling. The interstices are filled and the surface is covered with bituminous cement. The material for the wearing surface is heated to about 250° F., spread while hot, and compacted by rolling with a 10-ton roller to a thickness of about 2 inches. The surface is then covered with a liquid bituminous cement, on which, while it is in a sticky condition, there is spread a layer of sand or stone dust to a depth of about ½ inch. The rolling is then repeated, after which the pavement is ready for use.

BRICK PAVEMENTS

95. Although brick was one of the first of the materials used for paving, it has not been extensively used for this purpose until recent years. It is not equal to granite as a paving material for roadways sustaining an exceedingly heavy traffic. A brick pavement, however, when constructed

in a proper manner and of suitable materials, forms a smooth durable surface well adapted to moderate traffic.

Many methods of construction have been tried. The best practice at present is to use a hydraulic-cement concrete foundation, a thin cushion coat of sand or hydraulic-cement mortar, a joint filler either of paving pitch or of hydraulic-cement grout, and expansion joints placed at intervals of about 50 feet and at the curbs.

96. Foundation.—Many kinds of foundations, such as sand, gravel, sand and boards, broken stone, etc., have been employed for brick pavements. They have all proved more or less defective, and experience shows that the foundation should in all cases be composed of hydraulic-cement concrete, constructed as described for granite-block pavement. In localities where broken stone and gravel are difficult to obtain, the aggregate of the concrete may consist of fragments of broken brick.

97. Cushion Coat.—A layer of fine, clean, dry sand should be spread on the concrete foundation to a uniform depth of $\frac{1}{2}$ inch, as a cushion coat to receive the bricks. It is essential that the sand for the cushion coat should be perfectly free from moisture; if necessary, it should be dried by artificial heat. The cushion coat is sometimes made as deep as 2 inches.

98. Form and Size of Bricks.—Paving bricks are made in two sizes. The size to which the term "brick" is applied is intended to be the same as that of ordinary building brick, which is about $8\frac{1}{2}$ in. $\times$ 4 in. $\times$ $2\frac{1}{2}$ in.; the size termed "blocks" usually measures 3 in. $\times$ 4 in. $\times$ 9 in. As regards the effect of size on the character of the pavement, there is no difference. The adoption of the building-brick size has an advantage in that underburned or otherwise defective bricks can be sold for building purposes. The form preferred at present is the rectangular, with square, rounded, or beveled edges. The sides are plain, or have grooves $\frac{1}{8}$ inch deep, or else letters or buttons projecting $\frac{1}{8}$ inch. The object of these projections is to facilitate the

placing of the joint filler, and the purpose of the grooves is to increase the holding power of the filler.

99. Laying the Bricks.—The bricks should be set edgewise on the cushion coat, with their sides and ends in close contact. They should extend in parallel courses across the street, with their lengths perpendicular to the axis of the street, and should be so laid that the bricks of adjoining courses will break joints by a lap of not less than 3 inches. At street intersections, the courses should extend diagonally, so as to be approximately at right angles to the traffic. After the bricks have been laid, the surface of the street should be sprinkled with water for about 15 minutes, the water being applied from a hose or can fitted with a rose spray. Shortly after the sprinkling, the surface of the pavement should be inspected, and all the bricks that appear wet or damp should be removed and replaced with new bricks.

100. Ramming.—After the bricks have been laid, every part of the pavement should be thoroughly rammed with hand rammers weighing not less than 50 pounds. The rammer must not be applied directly on the surface of the brick, but on a plank $1\frac{1}{2}$ inches thick laid on the surface of the pavement, with its length parallel to the curb. The ramming should not approach nearer than about 25 feet to the edge of the new pavement that is being laid. All bricks that sink below the general level of the surface of the pavement should be taken up, and sufficient sand should be added to the cushion coat beneath to bring them to the required height.

As ramming by hand is expensive, and the results are not altogether satisfactory, it is now the practice to compress the bricks by using a steam roller of the same type as that employed for compacting asphalt, and weighing from 2 to 5 tons. It is advantageous to pass a light hand roller over the pavement before applying the steam roller; this prevents the displacement of the bricks under the heavy roller. The rolling should begin at the center of the pavement, and be carried on lengthwise of the pavement, working alternately

in opposite directions on each side of the center toward the edges. It should be so conducted that at each trip a part of the strip previously rolled is lapped by the roller, and should be continued until no settlement is observable.

101. Filling the Joints.—When the bricks have been settled to a firm and solid bearing by ramming or rolling, the joints are filled full either with a grout composed of equal parts of hydraulic cement and fine, clean, sharp sand, or with a tar filler composed of No. 6 coal-tar distillate. After the joints have been filled, the entire surface is covered with a layer of sand $\frac{1}{2}$ inch deep, which after a few days is swept up and removed.

CITY SURVEYING

MEASURING INSTRUMENTS AND METHODS

INTRODUCTION

1. The surveying work to be done by a city engineer or surveyor includes surveys for street, block, and lot grading; surveys for sewers, buildings, waterworks, bridges, and other structures; surveys for street railways; and land surveys. The land surveys may be small in extent, embracing the location of a single small lot, or they may be extensive, including the subdivision of large tracts of land into streets and building lots. Lot surveys in a large city compactly built on irregular lines are often very difficult, and demand not only very great precision, but a good deal of ingenuity in overcoming obstacles. The lines must not infrequently be carried over the tops of houses to determine interior angle points, each case presenting new problems not to be foreseen, and requiring much skill and judgment for their solution.

Surveys for the various forms of construction, for grades, etc. require no greater degree of precision than similar surveys out of a city, except where the determination of land lines is involved, as in laying out a building whose walls are to be erected exactly on the lot lines. Such surveys require the same degree of precision as city land surveys. This precision depends on the importance and value of the property. The value of 1 square foot of land in the country may be from less than $\frac{1}{16}$ cent to a probable maximum of 4 or 5 cents,

while in the heart of a large city a single square foot may be worth several hundred dollars. An error of 1 inch in the location of the wall of a modern high office building may be a very serious matter. The corner of a farm may be anywhere inside a tree 2 or 3 feet in diameter; the corner of an important city lot must be determined within the diameter of a builder's chalk line.

LINEAR MEASUREMENTS

2. The Tape.—Tapes of various kinds are described in *Chain Surveying*. The steel tape is the standard instrument for linear measurements in city work. The usual lengths are 50 and 100 feet. The tape may be graduated into feet, tenths, and hundredths; into feet and tenths; into whole feet with the divisions at the ends subdivided into tenths and hundredths; or in any other convenient manner. The manufacturer will graduate the tape to order.

Each time the tape is brought in after being used, it should be cleaned, if very dirty, with waste or a dry rag, and then carefully wiped off with a piece of cloth or chamois and a very small quantity of some non-gumming oil.

The tape has sometimes attached to it a handle that contains a spring balance for measuring the pull on the tape, a level bubble to guide in holding the tape so it will be level, and a thermometer to show the temperature of the tape. The thermometer scale may be so made as to indicate the proper pull to be exerted on the tape to make it of standard length for the temperature indicated. It is a question, however, whether such a scale can be relied on for precision, and hence its utility is of doubtful value.

3. Marking Pins.—The marking pins, where any are used, may be shorter and lighter than those used in country surveys. Pins 6 to 8 inches long made of No. 10 or No. 12 wire are good. In the larger cities, pins cannot be used, and lengths are indicated by knife scratches or pencil marks on the stone curb or pavement. A hard scratch awl answers the purpose very well.

CORRECTIONS

4. To measure a line with a high degree of precision is not difficult, but requires great care. In small town work, the absolute length of the tape is not usually known or required to a greater degree of precision than is furnished by the maker. The tapes sent out from reliable makers are compared with standards and may be assumed to be standard length when straightened out tight, with no stretching pull, at the temperature stated by the maker—usually 62° F. For important city work, the temperature at which the tape is exactly its graduated length should be determined by a test in a responsible testing laboratory, such as the Bureau of Standards in Washington, which for a small charge will furnish the constants of temperature and pull for any tape.

5. Correction for Temperature.—When the temperature of a tape rises, the tape expands or lengthens; when the temperature falls, the tape contracts. The proportion of its own length by which a tape changes in length for a change of 1° of temperature is called the **coefficient of expansion,** or **temperature coefficient,** of the tape. When practicable, the coefficient of expansion should be directly determined for each tape. For a steel tape whose coefficient is not known, .0000065 may be taken as an approximate value. That is, for an increase of 1° in temperature, the tape will increase in length by $\frac{65}{10000000}$ of its length, and will similarly shorten for a decrease of 1°.

Let t_0 = temperature at which a tape of length L_0 is **standard**—that is, at which the actual length of the tape is the length L_0 indicated by the figures on the graduations;

c = coefficient of expansion of tape;

L = length of tape at any temperature t.

Then, the *algebraic* increase in the length of the tape will be

$$cL_0 \times (t - t_0);$$

and, therefore, $$L = L_0 + (t - t_0)cL_0 \qquad (1)$$

The true length of every foot division of the tape will be $1 + c(t - t_0)$. Therefore, if the length of a line, as measured with and indicated by the tape, is l, and the true length of the line is l_0, we must have

$$l_0 = l[1 + c(t - t_0)] = l + c(t - t_0)l \qquad (2)$$

If t is less than t_0, the correction $c(t - t_0)$ is negative, which shows that l_0 is less than l. This is otherwise evident, since in this case the tape contracts, and therefore the indicated length is greater than the true length.

EXAMPLE.—A line was measured with a tape that was standard at 62°. The temperature was 90°. The length, as measured, was 502.34 feet. If the coefficient of expansion of the tape was .0000065, what was the true length of the line?

SOLUTION.—Here

$$c(t - t_0) = .0000065 \times (90 - 62) = .000182$$

The correction $c(t - t_0)l$ is, practically, $.000182 \times 502$, the decimal .34 being dropped, as the product of it by .000182 is too small to be considered. Therefore,

$$l_0 = 502.34 + .000182 \times 502 = 502.43 \text{ ft. Ans.}$$

6. Correction for Pull.—As explained in *Strength of Materials*, Part 1, if any elastic body is deformed by an external force, the deformation will disappear on the removal of the force, provided that the intensity of stress produced does not exceed the elastic limit of the material of which the body is formed. Within the elastic limit of the material of which a tape is made, the tape will stretch proportionally to the pull on it. If the length of the tape is denoted by L, the cross-section by A, and the modulus of elasticity by E, the elongation e caused by a pull P is given by the formula (see *Strength of Materials*, Part 1)

$$e = \frac{P}{EA}L \qquad (1)$$

Therefore, the true length L_0 of the stretched tape is given by the formula

$$L_0 = L + \frac{P}{EA}L \qquad (2)$$

If the length of a line as measured with the stretched tape is l, and the true length of the line is l_o, then

$$l_o = l + \frac{P}{EA} l \qquad (3)$$

For such steel as tapes are made of, E may be assumed without great error as 28,000,000 pounds per square inch. A not unusual cross-section is about .002 square inch. A tape 100 feet long with such a cross-section would be lengthened about .036 foot for a pull of 20 pounds above the normal. Hence, a line measured with such a tape under such a pull, and found to be 400 feet long, would really be 400 + 4 × .036 = 400.144 feet long.

7. Correction for Sag.—If a tape is held off the ground so that it is supported only at each end, it will sag and hang in a curve. Now, should the actual distance between the two supports, that is, the length of the chord made by the curve of the tape, be taken as equal to the nominal length of the tape, an error is made equal to the difference between the length of the arc and the chord of that arc. It is true that the tape may be pulled so hard that most of the sag may be taken out, but it is a physical impossibility to pull it so strongly as absolutely to remove all the sag. It is not difficult, however, to stretch the tape so as to take up most of the sag and make the nominal or graduated length of the tape practically equal to the true distance on the chord between the end graduations. The effect of sag in shortening the distance between end graduations depends on the weight and length of the unsupported part of the tape, and on the pull exerted at the ends of the tape. The derivation of a formula for this effect, which may be called the **correction for sag**, involves principles of advanced mathematics, and here only the formula itself will be given.

If L_o = unsupported length of tape;
w = weight of tape per unit of length;
P = pull;

the shortening s due to the sag is given by the formula

$$s = \frac{w^2 L_o^3}{24 P^2} \qquad (1)$$

It should be observed that L_0 is the length of the *unsupported part*, which may not be the entire length of the tape.

Since, when the tape sags, the distance between its two supports, as indicated by the nominal length of the tape, is greater than the actual distance, or the length of the chord subtended by the arc, the correction for the sag is negative, and must be subtracted from the nominal length indicated by the tape. If the length of a line, as measured, contains n times the length L_0, and the sag is the same in all measurements, the correction for sag is

$$n\,s = \frac{n\,w^2 L_0^3}{24\,P^2} \qquad (2)$$

EXAMPLE.—A line as measured with a 100-foot tape weighing .007 pound per foot, with a pull of 14 pounds, is found to be 400 feet. To determine the correction for sag.

SOLUTION.—Here, $n = 4$; $w = .007$, $L_0 = 100$; and $P = 14$. Substituting these values in formula 2,

$$n\,s = \frac{4 \times .007^2 \times 100^3}{24 \times 14^2} = .042 \text{ ft. Ans.}$$

8. Pull Necessary to Neutralize the Sag.—If it is desired to pull the tape just enough to cause the stretch, which is a positive error, to balance the sag, which is a negative error, the proper pull may be found by equating the expression for stretch (Art. 6) to that for sag, and solving the resulting equation for the pull P; thus:

$$\frac{P\,L_0}{A\,E} = \frac{w^2 L_0^3}{24\,P^2};$$

whence
$$P^3 = \frac{A\,E}{24}\,w^2 L_0^2;$$

and, therefore,
$$P = \sqrt[3]{\frac{w^2 L_0^2 A\,E}{24}}$$

As already stated, L_0 is the unsupported length of the tape, not necessarily the whole length.

EXAMPLE.—The weight of a 100-foot tape is .008 pound per foot, and the sectional area is .002 square inch. Taking E as 28,000,000 pounds per square inch, determine the pull necessary to neutralize the sag.

SOLUTION.—In this example, $w = .008$, $L_0 = 100$, $A = .002$, and $E = 28{,}000{,}000$. Substituting these values in the formula,

$$P = \sqrt[3]{\frac{.008^2 \times 100^2 \times .002 \times 28{,}000{,}000}{24}} = 11.4 \text{ lb. Ans.}$$

EXAMPLES FOR PRACTICE

1. A line is measured at a temperature of 80° and found to be 870.45 feet long. If the tape used is standard at a temperature of 60°, what is the true length of the line, taking the coefficient of expansion as .0000065? Ans. 870.56 ft.

2. What is the true length of a 100-foot tape, .002 square inch in cross-section, under a pull of 18 pounds, assuming the coefficient of elasticity to be 28,000,000 pounds per square inch? Ans. 100.032 ft.

3. What is the error due to sag in one-half of a 100-foot tape whose weight is .007 pound per foot, under a pull of 20 pounds? Ans. .003 ft.

4. What pull is necessary to neutralize the sag in a 50-foot tape whose sectional area is .002 square inch and weight .008 pound per foot? Assume the coefficient of elasticity to be 28,000,000 pounds per square inch. Ans. 5.7 lb.

MEASURING ON SLOPING GROUND

9. General Method.—In measuring on a slope, the method described in *Chain Surveying* may be used, if not very accurate results are desired. For very accurate work, it is preferable to measure directly along the slope, and then reduce the results to horizontal measurement. The process is illustrated in Fig. 1, where it is desired to determine the horizontal distance d $(= AH)$ between the points A and C. Stakes are driven at A and C, and at as many intermediate points as necessary, so that the distance between two consecutive stakes can be conveniently measured with the tape. In the case here assumed, there is an intermediate stake at B. The inclined distances l_1 $(= MN)$ and l_2 $(= NP)$

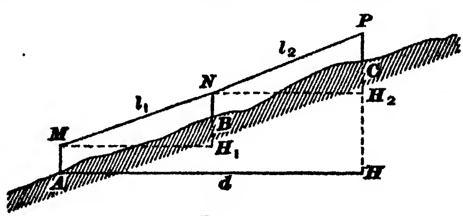


FIG. 1

between tacks on the tops of the stakes are carefully measured with the tape. The differences of elevation $h_1 (= NH_1)$ and $h_2 (= PH_2)$ are determined by leveling. Then,

$$d = MH_1 + NH_2 = \sqrt{l_1^2 - h_1^2} + \sqrt{l_2^2 - h_2^2}$$

The same method applies when there are any number of intermediate stakes.

10. Special Case.—When the slope of the ground is very gentle, the difference in elevation between two points is relatively small, and the horizontal distance does not differ very materially from the inclined. Under such conditions, the following formula gives sufficiently close results: Let l, Fig. 2, be the inclined distance between two points A and B whose difference h in elevation is small. Let the horizontal distance AC be denoted by d, and the difference $l - d$ by k, so that

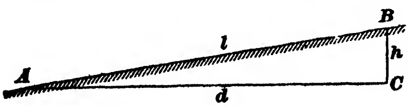


FIG. 2

$$d = l - k \qquad (1)$$

In the right triangle ABC,

$$l^2 - d^2 = h^2, \text{ or } l^2 - (l - k)^2 = h^2;$$

that is, $$2\,lk - k^2 = h^2;$$

or, approximately, since k^2 is very small,

$$2\,lk = h^2; \text{ whence } k = \frac{h^2}{2\,l}$$

This value in equation (1) gives

$$d = l - \frac{h^2}{2\,l}$$

ANGULAR MEASUREMENTS

11. The City Transit.—The transit is the only angle-measuring instrument employed in city surveys. The ordinary style of transit having a vernier reading to 30 seconds is the one most commonly used, though many are in use that read to minutes, a few that read to 20 seconds, and still fewer that are of special patterns. Since magnetic bearings,

except for rough checks, are used but very little, the needle may be dispensed with, and a stiff form of standards for the telescope may be made to bear directly over the center of the instrument, as shown in Fig. 3.

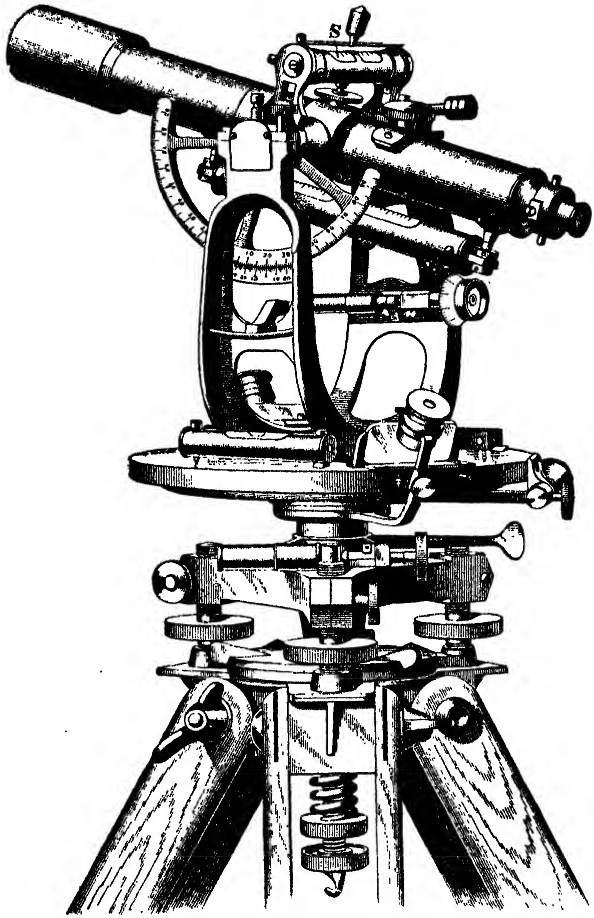


FIG. 3

The instrument shown has only three leveling screws, but four may be had if desired. It has also an inverting telescope; that is, the object looked at appears upside down and right side left. The three leveling screws give a broader

leveling base and a consequent greater precision in leveling; while the inverting telescope gives more light, and hence enables the operator to get a clearer conception of the object in view. The reason why the telescope gives more light is that the eyepiece is equipped with two instead of four lenses, and each lens absorbs some of the light rays that reach it. In the instrument shown in Fig. 3, the verniers have over them stationary glasses that are a great convenience in taking readings. The instrument is also equipped with a **striding level** *S*, which rests on the horizontal axis and is held in place by a screw in the center of the telescope. This striding level indicates at all times whether the transverse axis of the telescope is horizontal.

The striding level requires adjustment, as does any other level. The adjustment may be tested in the following manner: Place the striding level on the horizontal axis, and manipulate it with the lower screws until the bubble is in the center; then reverse the level end for end. If the bubble remains in the center, the level is in adjustment, and the transverse axis of the telescope is horizontal. If the bubble is not in the center, adjust the level with the screws provided for this purpose, lowering or raising one end until the bubble moves half way back to the center of the tube; then relevel with the leveling screws, and repeat for a check. There are adjusting screws for lateral adjustment, which is performed in the same way as the lateral adjustment of the wye level.

12. Every transit for city work should be provided with a vertical arc or circle, a clamp and slow-motion screw for the vertical motion of the telescope, and a bubble under the telescope. The vertical arc or circle should be fixed in position on the transverse axis, and should be provided with a vernier reading to minutes. The bubble under the telescope should be fairly sensitive, showing about 20 seconds of arc for a movement of the bubble over one division of the graduations on the tube. Fixed stadia wires set apart one one-hundredth of the focal length of the objective are desirable. The telescope should magnify not less than 22 diameters.

13. Line Rods.—The line rods used in city work should be of small diameter and perfectly straight. Probably the best rod is a $\frac{3}{8}$-inch hexagonal steel rod 6 feet long, painted in 1-foot lengths alternately red and white, and drawn to a sharp round point on one end used for the bottom, and to a blunt chisel point on the other. A chaining pin, a lead pencil, or a suspended plumb-line are often used instead of rods.

14. Measuring Angles.—For most surveying work, a single measurement of an angle with a minute-reading circle is sufficient, although every angle should be measured twice for a check; but in city work, angles are usually required to a smaller unit than the least reading of the vernier. These angles may be obtained by the **method of repetition** as follows: The transit is set up over the vertex of the angle with the verniers reading zero; the lower clamp being loosened and the upper set, the telescope is directed along the left-hand side of the angle. The lower clamp is then fastened, the upper loosened, and the telescope directed along the right-hand side of the angle. The upper clamp is now set, the vernier read, the lower clamp loosened, and the telescope directed along the left-hand side of the angle. The lower clamp is then set, the upper loosened, and the telescope directed along the right-hand side of the angle. The upper clamp is now set, the lower loosened, and the telescope directed again along the left-hand side of the angle; then the lower clamp is set, the upper loosened, and the telescope directed along the right-hand side of the angle. The process is repeated as often as necessary to obtain the required accuracy. The vernier is read after the final turning, when the telescope is set on the right-hand side of the angle, and the reading is divided by the number of turnings, including the first. The result will be the value of the angle, which, as a check, should closely approximate the first reading. This first reading is taken only for the purpose of checking the final result.

Theoretically, the number of measurements should be such that the sum will approximate a whole number of complete

revolutions, so that all parts of the circle may be used in measuring; but, practically, three measurements are sufficient in all ordinary cases. In very precise work, the angle may be read as described, and then read again from right to left with the telescope inverted. This eliminates errors of pointing and adjustment of the line of collimation.

15. Adjustment of Measured Angles of a Triangle. It is frequently necessary, in precise plane surveying, as in locating bridge piers, making topographical surveys of cities, etc., to measure triangles. When this need occurs, each angle of the triangle should be measured directly. If but two angles are measured and their sum is subtracted from 180° to get the third, all errors of measurement of the two angles are thrown into the third angle. When all the angles are measured to a high degree of precision, their sum will ordinarily be more or less than 180°, indicating an impossible triangle. To make the triangle possible, the angles are adjusted so that their sum shall be 180°. As stated in *Hydrographic Surveying*, the adjustment is effected by dividing the total error equally among the three angles. It might seem that a distribution in some ratio to the size of the angles should be adopted; but the method applied considers that there is no more reason for making an error in measuring a large angle than in measuring a small angle, which is probably true. Much more elaborate methods of adjusting angles are used where a network of triangles occurs, as in geodetic surveying, but the treatment of such adjustments is beyond the scope of this work.

PRECISION

16. Mean Value.—If a quantity, as a distance or an angle, is measured very accurately several times by the same method, it is usually found that the results vary slightly from one another. The true measure of the quantity is taken to be the mean of the different results obtained—that is, the sum of these results divided by their number. This mean is called the **mean value, or most probable value,**

of the quantity. Thus, if a distance has been measured five times by the same method and under the same circumstances, and the results have been, respectively, 75.83, 75.81, 75.84, 75.81, and 75.82 feet, the mean value of the distance is

$$\frac{75.83 + 75.81 + 75.84 + 75.81 + 75.82}{5} = 75.822 \text{ feet}$$

In operations of this kind, much labor is saved by finding the mean of only those figures that are different for the different measurements, and adding the result to the common part. In the example given above, 75.8 is the common part; it is, therefore, sufficient to take the mean of .03, .01, .04, .01, and .02, which is

$$\frac{.03 + .01 + .04 + .01 + .02}{5} = \frac{.11}{5} = .022$$

The mean value is, then, 75.8 + .022 = 75.822 feet.

17. Probable Error.—The mean value of a quantity, determined as just explained, may not be the exact value of the quantity. There is a quantity, whose value is determined by a formula derived by higher mathematics, such that there is the same probability of the true error being less as of its being greater than that quantity. Such quantity is called the **probable error.** The probabilities are that the error committed in taking the mean for the true value does not exceed the probable error—hence the name of the latter quantity. The probable error serves as a measure of the accuracy of the results obtained by the use of the mean value.

If each of the values found by actual measurement is subtracted from the mean value, a series of differences v_1, v_2, v_3, etc., called **residuals,** will be obtained. Let the sum of the squares of these residuals be denoted by Σv^2, the number of measurements by m, and the probable error by p. Then,

$$p = \pm .6745 \sqrt{\frac{\Sigma v^2}{m(m-1)}}$$

If the mean value is denoted by M, the probabilities are that the true value lies between $M + p$ and $M - p$. The

expression $M \pm p$ is often written as the value of the quantity, the term $\pm p$ being added simply to indicate the limits between which the true value probably lies.

EXAMPLE.—A distance was measured four times, the results of the measurements being, respectively, 501.07, 501.06, 501.05, and 501.08 feet. To determine: (*a*) the mean value M of the distance; (*b*) the probable error p.

SOLUTION.—(*a*) Since 501 is common to all the measurements, we have

$$M = 501 + \frac{.07 + .06 + .05 + .08}{4} = 501.065. \quad \text{Ans.}$$

(*b*) To apply the formula for p, we have $m = 4$, $m - 1 = 3$, and

$$\begin{aligned} v_1 &= 501.065 - 501.07 = -.005 \\ v_2 &= 501.065 - 501.06 = .005 \\ v_3 &= 501.065 - 501.05 = .015 \\ v_4 &= 501.065 - 501.08 = -.015 \end{aligned}$$

$$\Sigma v^2 = (-.005)^2 + (.005)^2 + (.015)^2 + (-.015)^2 = .0005$$

Therefore, $p = \pm .6745\sqrt{\frac{.0005}{4 \times 3}} = \pm .0044$. Ans.

18. Weighted Measurements.— If the measurements are not made under the same conditions, so that there are reasons to believe that some of them are more accurate than others, the results must be *weighted*, as in the adjustment of notes for balancing a survey (see *Compass Surveying*, Part 2). That measurement whose accuracy is supposed to be the least is usually given a weight of 1; a measurement whose accuracy appears to be twice as great is given a weight of 2; etc. After the measurements have been weighed, each measurement is multiplied by the number representing its weight, the products are added, and the sum is divided by the sum of the weight numbers. This result is the mean value, or most probable value, of the quantity. Thus, in the example given in the last article, if the first measurement is of the least weight, while the second is twice as great as the first, and the third and fourth are each two and one-half times as great as the first, the weights of the four measurements are, respectively, 1, 2, 2.5, and 2.5, and the mean value M is

$$501.0 + \frac{.07 \times 1 + .06 \times 2 + .05 \times 2.5 + .08 \times 2.5}{1+2+2.5+2.5} = 501.064$$

Giving the weight 2 to a measurement is equivalent to counting that measurement as two equal measurements of weight 1; the weight 2.5 is equivalent to two and one-half equal measurements (if such a thing were conceivable) of weight 1; etc. Therefore, in the probable-error formula, the square of each residual should be multiplied by the weight attached to the corresponding measurement; the sum of the products is used instead of Σv^2, and the sum of the weights instead of m. If the weights are denoted by h_1, h_2, h_3, etc., their sum by Σh, and the sum of the products $h_1 v_1^2$, $h_2 v_2^2$, etc. by $\Sigma(h v^2)$, the formula for the probable error becomes

$$p = \pm .6745\sqrt{\frac{\Sigma(h v^2)}{(\Sigma h - 1)\Sigma h}}$$

EXAMPLE.—To determine the probable error p in the example of the preceding article, the weights of the four measurements being, respectively, 1, 2, 2.5, and 2.5.

SOLUTION.—The mean value M has been found to be 501.064. The values of the residuals are as follows:

$$v_1 = 501.064 - 501.07 = -.006$$
$$v_2 = 501.064 - 501.06 = +.004$$
$$v_3 = 501.064 - 501.05 = +.014$$
$$v_4 = 501.064 - 501.08 = -.016$$

Then,

$$\Sigma(h v^2) = 1 \times (-.006)^2 + 2 \times (+.004)^2 + 2.5 \times (+.014)^2 + 2.5 \times (-.016)^2 = .001198, \text{ and } (\Sigma h - 1)\Sigma h = 7 \times 8$$

Substituting in the formula,

$$p = \pm .6745\sqrt{\frac{.001198}{8 \times 7}} = \pm .0031. \quad \text{Ans.}$$

19. Measure of Precision.—It will be seen from what precedes that the probable error furnishes a useful index of the precision with which the observational work has been executed. It is customary to express precision in terms of the probable error: when it is said that a line has been measured with a precision of $\frac{1}{5000}$, it is usually meant that the probable error derived from the series of measurements is not numerically greater than $\frac{1}{5000}$ of the determined length of the line. Thus, in the example of Art. **17**, the precision was $.0044 \div 501.065 = \frac{1}{113878}$. When the measurements were assigned such weights as were assumed to be proper (Art. **18**), the precision was $.0039 \div 501.064 = \frac{1}{128478}$.

The student should distinguish carefully between *accuracy*, referring to freedom from *mistakes*, and *precision*, referring to *refinement* or *closeness* of measurement. Thus, work may be as accurately done with a transit reading to minutes as with one reading to half minutes, but the possible precision with the latter is the greater.

20. Precision Required.—In important cities, a precision of 1 in 50,000 should be obtained in land-surveying measurements; that is, the mean of two measurements of a given line should have a probable error of not more than $\frac{1}{50000}$ of the length of the line. This will generally be accomplished if the two measurements differ by not more than $\frac{3}{50000}$, or, say, $\frac{1}{16000}$, of the length of the line. This result is not very difficult to secure if the proper methods and instruments are used. In villages and small towns, a precision of $\frac{1}{5000}$ is ordinarily sufficient, but it is so easy to secure a better precision than this, that no two measurements of the same line should differ by more than $\frac{1}{10000}$ of its length, giving a precision of the mean of the two measurements of about $\frac{1}{30000}$.

21. Precision in Angular Measurements.—In order that the direction of a line may be determined so that a distant end shall not depart from its true position by not more than $\frac{1}{50000}$ of the length of the line, the angle on which the direction depends must be measured to about the nearest 4 seconds. A transit reading to 30 seconds will permit an approximation to this result if the mean of three readings of the angle is used. An instrument reading to 20 seconds will ordinarily, by a triple measurement, permit a little closer results than the required one, and one reading to 10 seconds may give the requisite precision with a single measurement, though at least two measurements should be made for a check on the accuracy of the work.

Ordinarily, the position of a point can be more precisely determined by linear than by angular measurement, and, therefore, the former method of determination is in general to be preferred.

CITY SURVEYS

LOT SURVEYS

22. Street Lines.—When, as in the country, a road is a boundary of a farm, the center line of the road is usually the precise boundary; but in the city, the boundary line of property adjoining a street is the side line of a street, known variously as the **property line, building line,** etc. The whole street, including the sidewalks, is the property of the municipality. In some of the older and larger cities, where not only the store buildings but the dwellings have been built on the street line without a dooryard, the local laws provide that a certain portion of the sidewalk area may be used for display windows, stoops and steps, etc., but in many cities the abutting owner is not permitted to encroach so much as 1 inch on the street area. In the western cities of the United States, the street lines have been laid out with much regularity, usually nearly or quite at right angles, and such regularity has often obtained in the later additions to the older cities of the eastern states; but in many of the older cities and towns no regularity prevails; streets are neither straight nor continuous nor of uniform width, and there may very likely be two separate points required to mark the intersection of the center lines of two intersecting streets. The lines usually spoken of with the reference to streets are the *center line*, the *curb line*, and the *property*, *building*, or *house line*. When the term *street line* is used without any qualification, the building line is usually meant.

23. Description of a City Lot.—City lots may be described by the **lot-and-block** or by the **metes-and-bounds** method. By the first method, the lot appears on a map filed for record as a certain parcel of a block bounded

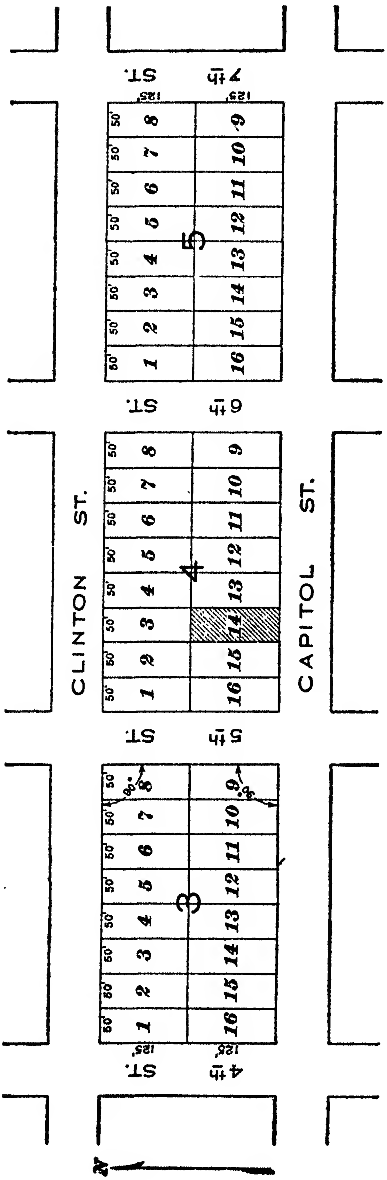


Fig. 4

by streets and designated by a number or letter; the lot also bears a number or letter, and its dimensions are shown on the map. The map bears a title, as, for instance, "Map of Bailey's First Addition to the City of Carthage," or, "Map of the Clermont Tract, City of Waterloo," with some further descriptive matter. Such a map is filed for record in the office of the county recording officer, either the county clerk, the county recorder, or some other officer that may be the custodian of records. The map bears the date of the survey and the date of filing.

Fig. 4 shows a portion of a map of an addition to a city, or a "tract." Supposing it to be the Clermont Tract in the city of Waterloo, filed for record in the office of the recorder of the county of Brown in the state of Ohio, on the 10th day of July, 1896, a description of the shaded lot by lot and block would be as follows:

Lot number 14 of block number 4 of the Clermont

Tract, as the same is shown and delineated on a certain map entitled, "Map of the Clermont Tract in the City of Waterloo" and filed for record in the office of the recorder of the County of Brown, State of Ohio, July 10, 1896.

24. By metes and bounds, the shaded lot in Fig. 4 would be described as follows:

Beginning at a point in the northerly line of Capitol Street, distant thereon easterly 100 feet from the easterly line of 5th Street, and running thence easterly along said northerly line of Capitol Street 50 feet; thence at a right angle northerly (or thence northerly and parallel with the said easterly line of 5th Street) 125 feet; thence at a right angle westerly (or thence westerly and parallel with the said northerly line of Capitol Street) 50 feet; thence at a right angle southerly, 125 feet to the place of beginning.

25. When maps are sufficiently definite, the lot-and-block method of description is to be preferred, particularly with regular subdivisions; since, if a surveyor in attempting to locate the lot measures the block and finds that he disagrees with the recorded length, he will divide the discrepancy among the several lots in locating the desired lot, while if the description is by metes and bounds, he is held rigidly to a beginning point (as 100 feet from the easterly line of 5th Street in Fig. 4), and a surveyor subsequently endeavoring to locate lot *13* from a description, using the westerly line of 4th Street as a basis, may find lot *13* overlapping or falling short of lot *14*, and trouble between owners results, or useless narrow strips are left to make trouble when assessments for street improvements are levied.

26. Encroachment.—Fences and buildings are not always on the lines on which they are supposed to be; they are often built over into the street area, or on adjoining owners' lots or property. These results occur through carelessness in building without a survey, or through the error of some surveyor. When an owner is thus using property, either public or private, that does not belong to him, he is said to be **encroaching.** Many street lines have been

materially altered by succeeding builders following the line of one building incorrectly placed. After erroneous lines have been in existence for many years, it becomes a serious matter to disturb them. They can usually be altered only by agreement between the owners concerned or by order of a court.

27. Statute of Limitations.—What is known as the **statute of limitations** is a state law providing that occupancy and apparent ownership for a certain definite period of time, varying in the different states, shall vest the title to the property in question in the apparent owner; so that, if a bounding fence has been out of place—an owner occupying a few feet or inches of his neighbor's ground—for the specified period of time, the erroneous position of the fence becomes the established position, the occupying owner becomes the real owner of the property in question, and the original owner loses his title to it. Of course, the owners may agree that the fence shall be reestablished in its correct position, and it will require an order of the court to establish the line legally in its erroneous position, but such order usually results from the contested effort of the losing owner to reestablish the disputed line in its correct position. The court will sustain the occupying owner in his contention that the actual or erroneous position of the fence is its correct position, and will so establish it in the records. The possession of such disputed property is called **adverse possession.**

28. Duties of Surveyors Concerning Encroachments.—The first duty of the surveyor with reference to encroachments is to study thoroughly the statute of limitations of the state in which he works. He is then prepared to give advice in any contest that may arise, but he must never, acting for either party, undertake to give a final decision. His position is simply that of an expert adviser whose duty it is to learn where the line should have been, the extent of the encroachment, and the time it has been maintained, and to report his findings with such disinterested advice as may be asked for. When such a boundary line has been finally

established by a court, it in no wise affects other lines that may have been dependent on its original position for their location. They will still be located from the original position of the line, if that position can be determined.

29. Relocating a City Lot.—The city surveyor that does lot surveying must be familiar with the monuments and descriptions of the city where he works. He must of course make a beginning without this knowledge, but his earlier work is much the more difficult by reason of his ignorance. His first step should be to familiarize himself with the records and maps of the various parcels of land, and, so far as he can, find from the records the location of the various monuments that have been set. In new cities, these monuments frequently consist only of wooden stakes set at the block corners, with no record of their existence, and the surveyor must be familiar with the customs of those that have preceded him in laying out the subdivisions. When he is called on to survey a lot, he will be furnished with such description as the owner has. This he should verify by referring to such maps of the tract in which the lot lies as may be on record, and to former deeds, which will probably be referred to in the deed of the present owner.

When he has obtained the records that exist concerning the tract, he will go to the nearest monument that he can find, and begin his survey. Just where he will measure—along the property line, the center line of the street, the curb line, or some arbitrary offset line—will depend on the location of the monuments and the existing obstructions. He should, in general, measure through the full length of the block in which the lot lies, to compare his measurements with the recorded measurements; and if the discrepancies he finds are not greater than he would expect in two measurements of the same line at different times by different men, he will distribute the discrepancy through the block in proportion to the recorded frontages of the several lots, making his measurements to locate the lot in question in accordance with such proportional distribution of the discrepancy.

Thus, if he finds that the block is .04 foot longer than the recorded length, and that the beginning point is in the middle of the block, he will make the distance from one corner to that point half of what he finds the length of the whole block to be; and if the beginning point is one-tenth the length of the block from one corner, he will make the distance one-tenth the length of the block as he finds it. In general, where possible, it is more accurate to measure along the front of the lot, establishing points on the side lines from the front line, or from the street line, than to attempt to measure from the end of the block along the front for the front corners and along the back for the back corners.

As an illustration of the methods of procedure, let it be supposed that lot *12*, Fig. 5, is to be located, stakes to be set at the four corners *a*, *b*, *c*, *d*. Apparently, two methods of locating these four corners are possible; first, locating *a* and *d* from the line *mp*, and *b* and *c* from the line *st*; second, locating all four corners from one of the lines, either *mp* or *st*.

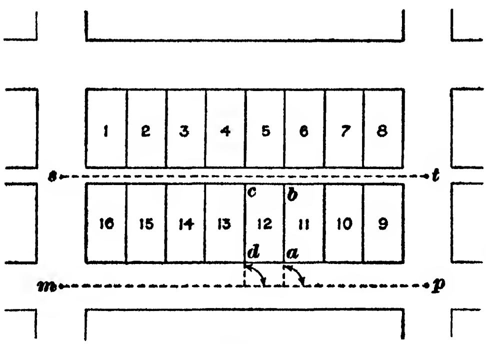


FIG. 5

Thus, by the first method, measurement would be made along the line *mp* from either *m* or *p* to points opposite *a* and *d*; the transit would be set over these points and angles turned from the line *mp* to *a* and *d*, respectively, and the offset distances from the line *mp* measured. The same procedure, using line *st*, would locate *c* and *b*. By the second method, using, for example, the line *mp*, measurement would be made as before to points opposite *a* and *d*, the transit set on these points, the proper angles turned from the line *mp* and measurements made to *a* and *b*, and *d* and *c*, respectively.

It is probable that the location of *b* and *c* will be rather better by the second than by the first method, and it is practically certain that it would be better if there are no monuments at *s* and *t*, as is the usual condition, necessitating, if the first method is used, measurements from *p* and *m* to the line of the alley, and measurements along the alley to locate *c* and *b*. If there are monuments at *s* and *t*, the first method may be as precise as the second, and if there are obstructions on the lines *a b* and *c d*, it will almost certainly be the better method.

30. The lot corners may be marked by stakes with tacks for temporary marks, or by stone monuments or iron pins if the corners are not to be occupied by a building or fence. Iron pins or stone monuments may be set in the sidewalk area on the extension of the side lines, or crow's-foot (↓) marks may be made in the curb. The permanent marking of the back corners is not generally required. Stakes with tacks usually answer the purpose, or marks may be made in the alley curb or paving.

31. When the discrepancies in the measurement of the whole block prove too large, and correct measurements in agreement with the description are in conflict with adjoining lines already located, the surveyor should report what he finds, after assuring himself that his own work is correct, and ask for further instructions, unless he is familiar with local practice in connection with these discrepancies. He should remember that he has no power to determine where a line must be; he can only give his judgment as to where it should be, leaving a court to decide where it shall be, in case the adjoining owners do not agree.

32. Certificate and Plot of Survey.—The result of a survey of a lot should be reported to the owner in somewhat the following form, blanks for which may be printed, leaving a space for drawing the map, and requiring only the name of the owner, the date, and the signature of the surveyor.

CERTIFICATE OF SURVEY

HABBERTON, OHIO,____________190___

I hereby certify that I have this day made a survey of the premises described as *Lot 26, Block 4, Turner's Addition to the City of Habberton,*

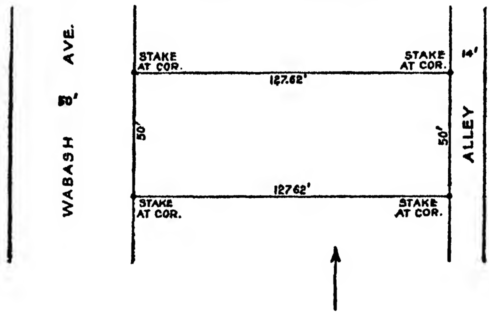


FIG. 6

and that I have found the lines and marked them as shown on the subjoined plot.

Survey made for________________________________

at request of________________________________

____

SURVEYOR

When, for building design and computations, the architect desires a complete survey, it is necessary to add to the data given in the ordinary lot certificate. The following items should appear on the plot:

1. Lines of the lot, with dimensions and angles in figures, and curb lines.

2. Grade of street, actual and established, and of the alley, if there is one.

3. Location, elevation, and size of sewer, with elevation of its flow line.

4. Location and size of gas and water mains.

5. Elevations at the corners of the lot, and more frequently if the ground is not flat. In this case, the lot may be divided into small squares and elevations taken at the corners and elsewhere if necessary.

6. All trees, if any.

7. The lines of adjoining buildings, with elevations of their floor levels.

8. Character of soil, whether rocky or underlaid with rock within a depth likely to be reached by the cellar excavations.

Fig. 7 is a lot map showing some of these details; all dimensions are supposed to be in feet. The figures in marks of parenthesis express elevations above an assumed datum.

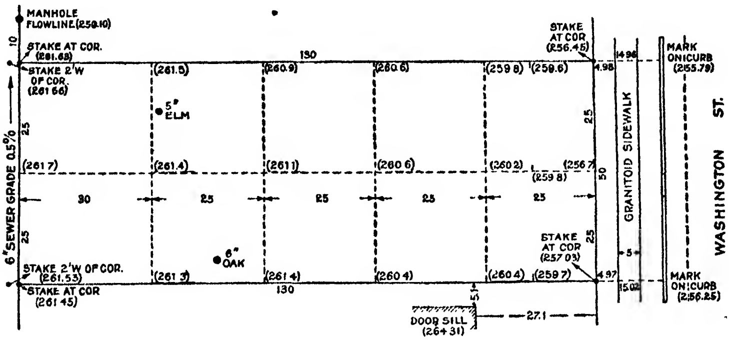


Fig. 7

If a building covers the lot, its outlines should be indicated with fine shading inside the lines, as shown in Fig. 8.

The certificate of survey should be on a piece of tracing cloth or tough linen tracing paper, cut to the size of a deed

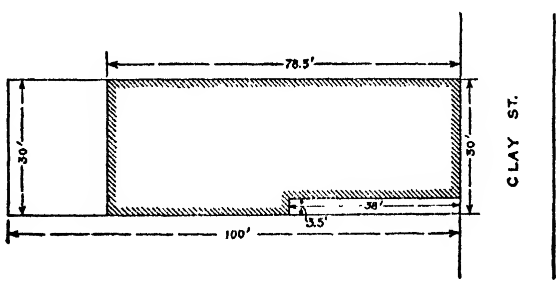


Fig. 8

blank, or legal cap. One or more prints from the tracing are filed for office use, the original being given to the client. The certificate may be folded like any legal document, and filed in a document filing case.

SUBDIVISIONAL SURVEYS

STREETS AND BLOCKS

33. General Street Plan.—The engineer is seldom called on to lay out a new town site likely to be covered by a large city, but occasionally this task comes to him, and he is frequently asked to plan and lay out additions to existing towns. In many respects, the principles governing the design of a street plan for a new town apply to the planning of a new addition. Some of these principles are here given.

A business district of comparatively small blocks and fairly wide streets should be surrounded with a residence area of larger blocks, generally large enough to make two business blocks with an intermediate street as the business district grows. The blocks should be rectangular, giving streets at right angles, about twice as long as wide, with directions such that a maximum of sunlight may reach streets and buildings. These directions may vary with the latitude, but in the temperate zone they should in general be diagonal with the cardinal points, that is, northeast and southwest and southeast and northwest. Streets thus laid out will all have sunlight for a considerable portion of each sunny day, though none of them will receive the noon rays. All four sides of every block will receive sunlight at some hour of every sunny day.

Radiating from the business district in at least four directions, north, south, east, and west, should be diagonal avenues of considerable width. These avenues, together with the rectangular streets, provide the shortest practical routes to the different parts of the city. At intervals of perhaps $\frac{1}{2}$ mile, there should be cross-avenues about at right angles to these diagonal avenues, and at the intersections of the two sets of avenues there should be park places of one or more blocks. Much of the direction of the streets may depend on the topography. The plan should be such as to secure reasonable grades, with no impassably steep hills,

with good drainage toward the streets and toward one or more main drainage lines serving as outlets for the drainage of the city.

34. Street Plan of the City of Washington.—The nearest approach in America to an application of these principles is the city of Washington. The plan of the city was originated by Major L'Enfant, a young officer of the engineering corps of the French army that aided the United

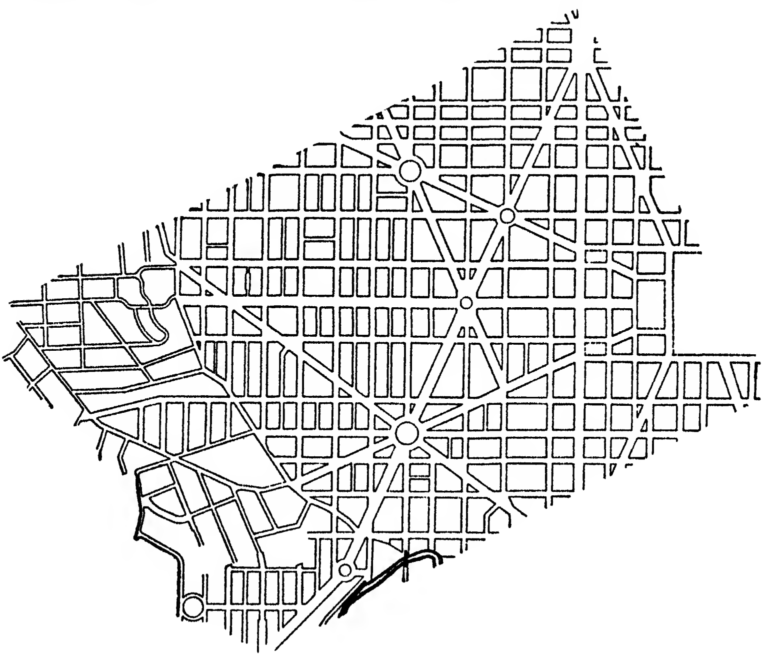


FIG. 9

States in its Revolutionary struggle. The plan was approved by President Washington, and laid out on the ground about 1791 by Andrew Ellicott; it has proved entirely adequate to the more than a century's development of a large and beautiful city.

Fig. 9 shows a portion of this plan. The main subdivision is rectangular, with streets extending north and south and east and west, intersected by numerous diagonal avenues,

providing fairly direct routes between any two portions of the city. From the center of the Capitol, the streets extending east and west are named in order A, B, C, etc., north and south, while those extending north and south are named in order First, Second, Third, etc., east and west, and the diagonal avenues are given the names of different states. The irregular, inconvenient, and inadequate streets shown at the left of the figure are the result of individual liberty in the laying out of additions. This liberty was somewhat tardily curtailed by legislative authority, and future additions must conform to the general plan of the city.

35. Size of Blocks.—A block may be any length not too great for the convenience of travel; about 480 feet from center to center of streets is a good length, though 660 and 400 feet are not uncommon lengths. The width will be the depth of two lots, or two lots plus the width of an alley, if there are alleys. Lot frontages may be anything desired; they are most frequently from 20 feet to 25 feet in business and congested residence districts in large cities, and from 50 to 150 feet in villages and small towns. They are usually an aliquot part of the net block length. The depth may be 100 feet in business and residence districts of large cities, and from 100 to 160 feet in villages and small towns not likely to grow large. Frontages and depths vary much with the ideas of the owners of property, and with the size of the tract; thus, there are residence lots 125 feet front by 60 feet deep—very awkward dimensions. For residence districts, lots should be of such width—unless they are of minimum width—that they will divide into a whole number of business lots of equal width; thus, a 50-foot lot will divide into two 25-foot lots; a 40-foot lot into two twenties; an 80-foot lot into four twenties, etc.; but a 35-foot lot is too large for a small business property, and too small for two business lots.

36. Widths of Streets.—Streets should be wide enough, from property line to property line, to accommodate travel and to permit the entrance of sunlight and air to the buildings on both sides. Principal business streets in large cities,

like New York, Chicago, Philadelphia, and St. Louis, should be 200 feet or more in width. Boulevards for driving, with a parkway through the middle, should be of a like width. Less important business streets may be 100 feet wide, and minor streets 80 feet. Residence streets should be not less than 60 feet—a common width—and need not be more than 80 feet in width. If street-car tracks are likely ever to be laid, even minor streets should be not less than 100 feet wide. The streets of most old cities are too narrow for convenience of travel, or for the entrance of light and air. This is partly due to the unforeseen growth of small villages; partly to the desire of owners to make the largest number of lots from their property; partly to the unforeseen increase in modern transportation lines; and partly to the fact that the necessity for light and air was not formerly so thoroughly appreciated as now.

37. Widths in the City of Washington.—In the city of Washington, the streets are generally 70, 80, 90, 100, and 110 feet in width, though one important street is 160 feet wide, and one short, unimportant street is only 40 feet wide. The avenues are generally 160 feet wide, though a few have widths of 130, 120, and 85 feet. The law now requires that, in laying out new streets and avenues, the width shall not be less than 90 feet for streets nor less than 120 feet for avenues. Intermediate streets, called **places**, may be laid out within blocks with a width of 60 feet, but the distance between full-width streets must not be more than 600 feet. Washington probably has the best and most liberal system of streets in America. The beneficial results of its liberal policy with regard to streets are evidenced by its large growth, by its popularity as a residence city, by the corresponding increase of property values, and by the great comfort enjoyed by its inhabitants.

38. Alleys.—Where laid out, alleys should be about 20 feet wide. Opinions vary as to the desirability of alleys. The argument for them is that they provide convenient access to residence and business property for the delivery of

materials and the removal of refuse, and afford convenient locations for sewers. The argument against them is that they are likely to become foul and unwholesome through neglect. Under properly enforced adequate regulations, alleys may be a convenience, but cases of such adequate control are so few that the weight of evidence is very much against the alley.

THE WORK OF SUBDIVISION

39. Preliminary Survey.—When a tract of land within or adjoining a city is to be subdivided into building lots, the first step of the surveyor is to look it over with the owner to decide what sort of subdivision shall be made, and the second step is to make an outline survey of the tract with a high degree of precision. It will doubtless be found that the new precise survey will differ from the former surveys made when the property was farm land; but, if the real boundaries can be found, the difference will be of no consequence, as a map of the subdivision, with the new and presumably correct dimensions, will be filed. The survey should be carefully balanced by the methods explained in *Transit Surveying*, Part 1, the angular work being so done in the field that it will close with an error not greater than the smallest reading of the transit.

The boundary survey should include the determination of the points of intersection of the lines of all existing streets that if produced would enter or cross the property, and the directions of those street lines. The work should be done by the usual method of traversing with the transit, using azimuths rather than bearings or deflection angles. The boundary survey should be plotted to a large scale by the method of latitudes and longitudes, the latitude and longitude of each corner from some arbitrary meridian and base, or from an established local meridian and base, being determined. If the tract is reasonably level and small, no topographical survey will be required; but if it is large and undulating, a topographical survey should be made with sufficient precision to permit drawing 2-foot contours with

some degree of accuracy. If the tract has any large trees, they should be located, so that they may be preserved if possible.

40. Planning the Subdivision of a Small Tract. If the tract is small—say, a block or so—surrounded by or adjoining the previously subdivided portions of the city, there is but one thing to do, and that is, to extend the intersecting streets through the property, unless such extension would work serious harm to it. In

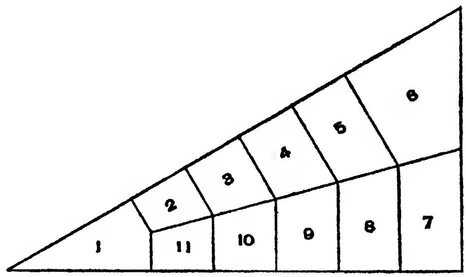


FIG. 10

some cities, as Washington, ordinances provide that all new subdivisions must conform to the surrounding subdivisions. When the property of adjoining owners does not permit of such subdivision without leaving small fractional gore-shaped lots, transfers between the owners may frequently be made with advantage.

After the boundary survey has been made, the outline is mapped to a large scale, the streets are drawn in, and the resulting blocks subdivided into lots of such size as may seem desirable. The distances must not be scaled from the map, but must be obtained by direct measurement in the field, or by computation from

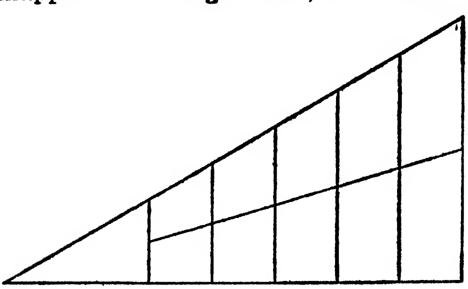


FIG. 11

such measurements and the measured angles. If the blocks are irregular, a scheme of subdivision should be adopted that will, as far as possible, produce parallel side lines at right angles to the front, leaving irregularities at the back line; and when it seems impossible to bring the side lines at right

angles to the front, they should still be kept parallel. Thus, the divisions of the two blocks shown in Figs. 10 to 13

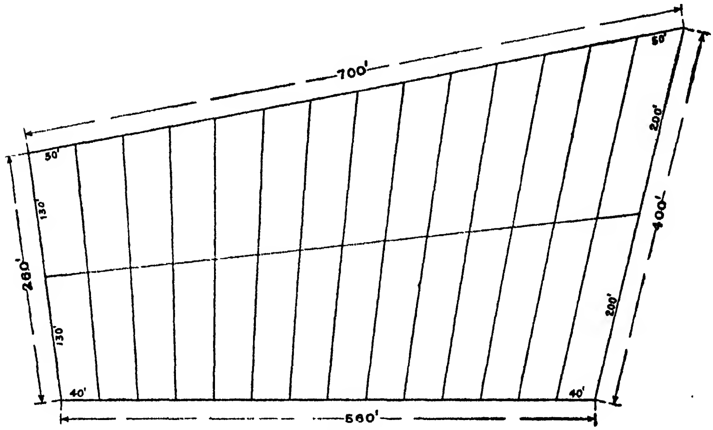


FIG. 12

should be as indicated in Figs. 10 and 13 rather than as shown in Figs. 11 and 12.

The dividing line at the back of the lots bisects the angle between the front lines. The irregular dimensions are all

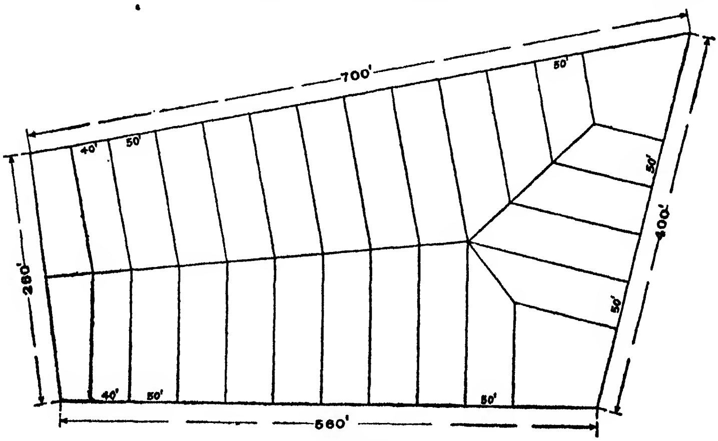


FIG. 13

thrown into the corner lots. The side lines of the lots on the two streets should meet at the back, so that lots may be

purchased through from street to street without offsets in them. Where alleys extend through the block, this is of course unnecessary.

In general, where blocks are rectangular, it is unwise to face the lots on more than two streets, as, if they are faced on three or four streets, there result what are known as **key lots**, that is, lots against whose sides lie the backs of other lots. In very large cities, the frontage value in business and even residence districts becomes so great that this rule is ignored.

Permanent monuments should be placed marking the block corners or street lines, in accordance with the customs or ordinances prevailing in the city. A map should be made showing the subdivision, the block and lot numbers, the streets, every dimension and angle necessary to relocate or determine any lot, the positions of all monuments placed and a description of those monuments, and such witness points as may be known, sufficient to enable another surveyor to find them. The title of the tract, the date of the survey, the scale of the map - both drawn and written—and the name of the surveyor should all appear on the map.

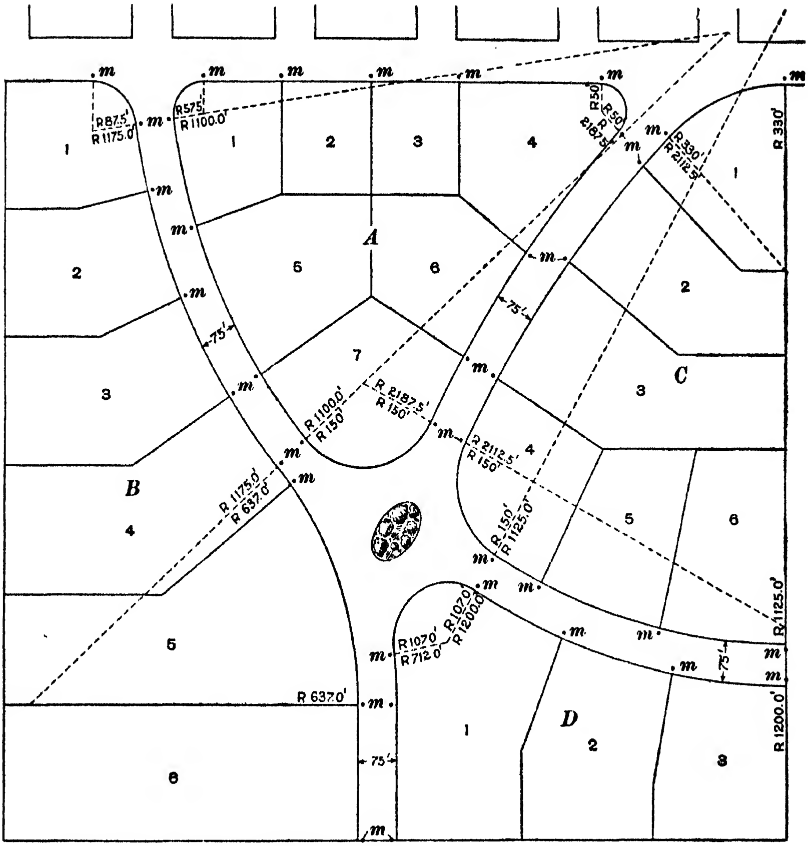
41. Planning the Subdivision of a Large Tract. If the tract is a large one, either within or without the previously subdivided city, and if the territory is fairly level, the surrounding or nearest street lines should be produced through the property; the work of subdivision is then essentially the same as that for a small tract. If, however, the ground is rolling, well out from the city, and almost certain for many years to be residence property, an irregular subdivision may be planned. This is a somewhat dangerous proceeding, especially if the tract is situated within any reasonable distance of a large and growing city, but is rather desirable in the case of a tract that is situated on the outskirts of a small town likely always to remain small or is at some distance from a large city. In this case, the subdivision will be based on the topography of the tract and on the character of residences desired. After the boundary

survey is finished, a careful topographical survey should be made by transit and stadia, by plane table, or by dividing the tract into parallelograms and using a wye level, as explained in *Topographical Surveying*. A contour map is made, preferably with contour intervals of not more than 2 feet, and on this map the streets and lots are plotted. In general, the streets should take the valley lines; there should be no angles, but easy graceful curves, and for a tract to be offered to well-to-do residents the lots should be large—none perhaps less than 1 acre in extent. If the tract is to be offered to persons of small means, the lots must be smaller; and when this is the case, the more closely the subdivision approaches a rectangular plan, the better.

42. In laying out curved streets, the curves should be arcs of circles, those of different radii joining with common tangents as compound railroad curves. At all changes of curvature, there should be referenced monuments set on the arcs or at uniform offsets from them on the radial lines produced. Long-radius curves should be used, except at street intersections, where the corners will be rounded with short radii. It is not usual to introduce alleys in curved subdivisions. To be entirely successful in laying out park-like subdivisions, a surveyor must have an artist's eye and some training in the principles of landscape architecture.

43. The general plan is first studied on the ground, then on the map, and a plan worked out on the map is again studied on the ground, to see that the property has been developed to the best advantage. The main streets are placed in the valley lines to insure easy and complete drainage, and to leave the more sightly hills for dwellings. After the plan has been finally determined, a finished map is made, the block and lot monuments are set, and the work is complete so far as the subdivision is concerned. As owners of such tracts frequently desire to grade the streets, lay sewers, water and gas mains, and sidewalks, the surveyor's work may include the staking out and supervision of such work, and the estimate of quantities. It is usually desirable to

make these improvements before placing the property on the market, since the increased selling value of the property is almost always considerably in excess of the cost of the improvements.



OUTLINE MAP OF CLERMONT PARK, showing Position of Monuments.— m = Monument.—4 ft. from Property Line.

FIG. 14

44. Fig. 14 will illustrate the foregoing description concerning curves and the positions of monuments. As far as possible, it is well, as indicated in the figure, to have all division lines radial that run back from the street lines. In

this subdivision, the division lines on the left of the tract are made perpendicular to the left outside boundary, to provide for the possible future opening of a street along that boundary line, and for the division of the frontage into smaller units. A finished map of such a tract should show all dimensions and angles, and it should be made to a scale large enough to permit these data to be given without confusion. The accurate computation of the lines and areas of such a tract is a very tedious operation, and the dimensions are more frequently than otherwise obtained by scaling from a large map, the areas being found by the use of the planimeter.

45. The Map.—Whether the tract is large or small, the map should be a complete and faithful record of the subdivision in every particular. A great many very imperfect maps have been made and filed—maps that are mere pictures and fail to give the data necessary for the description or relocation of the various parcels shown. A map that is to serve as a basis for descriptions of property in transfers and for the location of the parcels transferred should contain two sets of data—one for the description and location, and one to insure the reliability of the data shown.

The first set of data should include:

1. The lengths of all lines shown.

2. The exact angle made by all intersecting lines.

3. The exact position and character of all monuments set, with notes of reference points.

4. The number of each block and lot.

5. The names of all streets, streams, or bodies of water, and recognized landmarks.

6. The scale.

7. The direction of the meridian, and a note as to whether the true or the magnetic meridian is shown. (It should be the true meridian.)

8. The angles made by the lines of adjoining property with the boundaries of the tract mapped.

9. A simple, complete, and explicit title, including the name of the surveyor, and the date.

The second set of data contained in the map should include:

1. The certificate of the surveyor that he has carefully surveyed the land, that the map is a correct representation of the tract, and that he has set monuments (to be described) at the points indicated on the map.

2. The acknowledged signature of all persons possessing title to any of the land shown in the tract, and, if possible, signatures of adjoining owners.

3. If of an addition, the acknowledged dedication to public use forever of all areas shown as streets, roads, or other public areas.

4. If a street of full width whose center line is a boundary of the tract is shown, the acknowledged signature of the owner of the adjoining property to his dedication of his half of the street, unless that half has been previously dedicated.

GRADING SURVEYS

46. Levels and Profiles.—Surveys for grade, either for street-surface grades or for sewer grades, consist simply in leveling and making profiles. For sewers, levels along the center lines of the streets will suffice, with now and then for every block an observation of the depth of cellar, that is, the elevation of the bottoms of the deepest cellars to be drained. In some great business buildings in very large cities, there are basements and subbasements below the level of the street sewers, and these must be drained by some form of pumping or ejecting plant; but, in ordinary cases, the sewers must be placed deep enough to drain the deepest cellars.

47. For street-surface grades, the levels should be taken as often as once in 100 feet—oftener if the changes in surface grade make closer points desirable—and at all street intersections. Three lines should be leveled on each street—the center line and the two block, or property, lines—and these should be plotted on one profile map in three different colors to distinguish them. If the street is level across, or essentially so, as is the case in some western cities of the United

States, elevations of the center lines will be sufficient. Perhaps the best scale for the profile is 100 feet to the inch for horizontal measurement, and 10 feet to the inch for vertical measurement; this scale fits cross-section paper ruled to inches and tenths. Cross-section paper is better than profile paper for street-grade profiles.

48. Setting Grade Stakes.—Grade and line stakes are set for all street grading and sewer construction, and sometimes, though not so generally, for water mains, gas mains, electric conduits, etc. Stakes set for street grading are placed at the edges of the excavation or embankment on the property or block line, and marked with the cut or fill needed to bring the points, when they are set, to grade. If the depth of the cut or fill is not too great, the top of the stake is driven to the grade elevation, or "to grade," excavating a little where necessary, or using a long stake for embankments; the stake, or a guard stake, is marked "grade." When the work nears completion, stakes centered with tacks are set for the curb lines and grade at intervals of 50 feet.

49. Trench stakes for sewers must give the line and grade. Perhaps the most convenient method is to set the stake about 2 feet from the edge of the trench at the foot of the pile of excavated earth, which will begin about that distance back from the edge. The face of the stake next the trench should be driven exactly to a definite offset from the center line of the pipe or sewer, and the top of it to a definite whole foot (where convenient) above the grade of the trench.

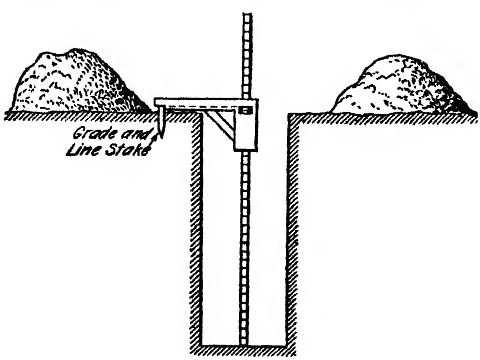


Fig. 15

By using an arm containing a small bubble, and a rod to slide through one end of the arm, the foreman, having a

record of the depth of grade below the stake, can finish his excavation to true surface without calling on the surveyor.

Fig. 15 illustrates the method just described. The distance from the shoulder on the arm that rests against the face of the stake to the center of the slot through which the rod slides, and hence to the center of the rod, is made equal to the length of the offset of the stake from the center line of the trench. A different arm may be provided for different offsets used with trenches of different widths, or an adjustable arm may be used. The bracket arm is built in to form a right angle. A small carpenter's level may be fastened to the top of the arm.

When the banks are of shelving earth, sheet piling is used, and the stakes, if placed too near the trench, are likely to be disturbed; they are then set farther away, and the line and grade of the trench must be given by the surveyor.

50. Surveys for Lot Grading.—When a lot or block is to be graded to a definite surface, and the volume of earth moved is to be computed, the usual method of procedure is as follows (see Fig. 16): The lot is divided into squares or rectangles so small that the surface of each rectangle or square may be considered plane. Stakes p are set in line with the subdivision lines, as shown outside of the block, in such positions that they will not be disturbed by the grading operations. The sides are numbered one way and lettered the other way. Any corner is designated by the letter and number of the lines intersecting at it, the number being attached to the letter as a subscript. Thus,

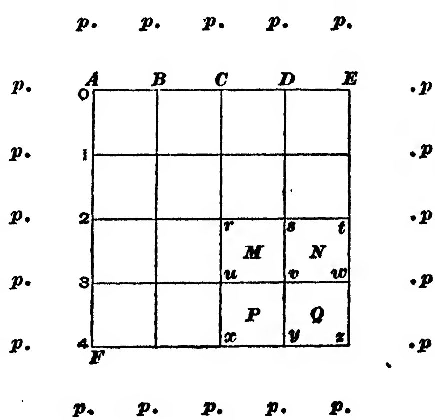


FIG. 16

the corner u is called C_3. The elevations of all the corners are determined next. The difference between the elevations before and after grading will be the depths of cut or fill at the several corners. The corners may be located on the ground after the grading, by lining from the stakes set outside the block.

51. Computation of Volumes.—Each rectangle shown in Fig. 16 is really the horizontal projection of the area included between the four stakes. When the soil is excavated to the required grade, the volume excavated is part of a prism cut at one end by the natural surface of the ground, and at the other by the grade surface. The horizontal projection of such prism (the corresponding rectangle shown in Fig. 16) is called the **right section** of the prism. The edges of the prism are the differences in elevation between the four corners on the natural surface of the ground and the corresponding corners of the graded surface. With the necessary change of terms, what has been said of excavation applies to fills.

The volume of each prism can be obtained by multiplying the area of its right section by the mean of the lengths of its four edges. The computation of the volume may be simplified by applying a formula that gives the sum of all the prisms. To show the application of the formula, let the four prisms whose right sections are M, N, P, Q be considered. If K represents the area of each rectangle, and the depth of cut or fill at a corner is represented by the letter at that corner, then, denoting the volumes by V_m, V_n, etc., we have

$$V_m = \frac{K(r+s+u+v)}{4}$$

$$V_n = \frac{K(s+t+v+w)}{4}$$

$$V_p = \frac{K(u+v+x+y)}{4}$$

$$V_q = \frac{K(v+w+y+z)}{4}$$

Adding, we have for the volume V_4 of the four prisms,

$$V_4 = \frac{K(r + 2s + 2u + 4v + t + 2w + x + 2y + z)}{4};$$

or, in cubic yards,

$$V_4 = \frac{K}{4 \times 27}[(r + t + x + z) + 2(s + u + w + y) + 4v]$$

The first parenthesis is the sum of all the corners used but once, or for but one prism; the second is the sum of all those used twice, or belonging to two prisms; while the v that is multiplied by 4 is the one height that belongs to all four prisms. If there had been a height belonging to three prisms—if, for instance, the prism Q had not been included—the height v would have been used three times, and hence multiplied by 3. From these considerations is derived the following general rule for computing the material excavated:

Rule.—*Add all the heights, in feet, belonging to a single prism, twice the sum of those belonging to two prisms, three times the sum of those belonging to three prisms, and four times the sum of those belonging to four prisms; multiply the sum by the area, in square feet, of one rectangle or right section, and divide the product by* 4×27 *to obtain the volume in cubic yards.*

This rule is general and gives the amount of *excavation*, in case all the corners are above grade. If all the corners are below grade, the result is the amount of *fill*. When some of the corners are above and some below grade, the heights of those below grade are considered negative, and the result is the amount of material *removed*, or the *difference* between the cut and the fill. If the result is positive, it shows that the cut is in excess, and, if negative, that the fill exceeds the cut. In estimating the cost, it is necessary to know both the cut and the fill; therefore, it is necessary to calculate one of these values separately, and, from it and the results obtained by the formula, to determine the other value. The method of procedure is illustrated by an example to be given presently.

In the lot represented in Fig. 16, the corners A, E, z, F would be used only once; each of the other outside corners, twice; and each of the interior corners, four times. No corner would be used three times.

EXAMPLE.—In the rectangular block shown in Fig. 17, the elevations found at the several corners are as follows:

A_0, 105.6	B_0, 104.0	C_0, 102.8
A_1, 103.8	B_1, 102.4	C_1, 101.5
A_2, 102.7	B_2, 101.6	C_2, 98.3
A_3, 100.8	B_3, 99.4	C_3, 97.2

It is desired to grade the block to a level surface of elevation 100. How much is utilized in filling the low portion, and how much is to be wasted or hauled away?

SOLUTION.—An inspection of the elevation shows that the surface is a rounded hillside sloping from the upper left corner A_0 toward the lower right corner C_3, and that the lower right portion must be raised or filled to bring it to elevation 100, while the greater part of the block must be lowered or cut. Between the portion to be filled and that to be cut there will be a line, more or less irregular, that will be just at elevation 100, and hence a grade line, or line of no cut or fill. An inspection of the corner elevations shows that this line will cut the C line between C_1 and C_2, the 2 line between 2_B and 2_C; the B line between B_2 and B_3, and the 3 line between 3_A and 3_B. To find the volume it will be necessary to determine just where this grade line crosses the sides of the several rectangles.

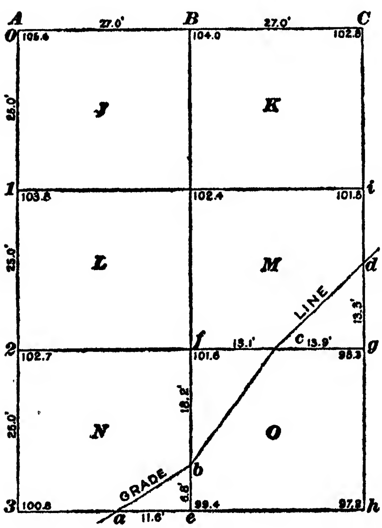


FIG. 17

Assuming that the slope is uniform from one corner to the next, the ground rises 3.2 ft. from g to i; hence d, elevation 100, or 1.7 ft. above g, will be $\frac{1.7}{3.2}$ of 25 ft., or 13.3 ft., from g toward i. Similarly, gc is found to be 13.9; fc, 13.1; fb, 18.2; be, 6.8; and ae, 11.6—all figured to the nearest tenth of a foot. First the amount wasted or

hauled away will be determined by applying the rule given in this article. The heights used but once are:

$$
\begin{array}{lrr}
A_0 = & +\ 5.6 & \\
A_3 = & +\ \ .8 & \\
C_3 = & & -2.8 \\
C_0 = & +\ 2.8 & \\
\hline
& +\ 9.2 & -2.8 = \quad +6.4
\end{array}
$$

The heights used twice are:

$$
\begin{array}{lrr}
A_1 = & +\ 3.8 & \\
A_2 = & +\ 2.7 & \\
C_1 = & +\ 1.5 & \\
C_2 = & & -1.7 \\
B_0 = & +\ 4.0 & \\
B_3 = & & -\ .6
\end{array}
$$

$$(+12.0 - 2.3) \times 2 = +9.7 \times 2 = +19.4$$

The heights used four times are:

$$
\begin{array}{lr}
B_1 = & +\ 2.4 \\
B_2 = & +\ 1.6 \\
\hline
& +\ 4.0 \times 4 = \quad +16.0
\end{array}
$$

$$+41.8$$

The volume of waste is

$$\frac{25 \times 27 \times 41.8}{4 \times 27} = 261.3 \text{ cu. yd.} \quad \text{Ans.}$$

The volume of the triangular prism of fill $c\,d\,g$ is

$$\frac{13.3 \times 13.9 \times 1.7}{2 \times 3 \times 27} = 1.9 \text{ cu. yd.}$$

Similarly, the volume of the triangular prism of fill $a\,b\,e$ is

$$\frac{6.8 \times 11.6 \times .6}{2 \times 3 \times 27} = .3 \text{ cu. yd.}$$

The difference between the cut and the fill on the rectangle O is

$$\frac{25 \times 27}{4 \times 27}(1.6 - .6 - 2.8 - 1.7) = -21.9 \text{ cu. yd.}$$

The negative value shows that the fill exceeds the cut.

The cut in the triangular prism $f\,b\,c$ is

$$\frac{18.2 \times 13.1 \times 1.6}{2 \times 3 \times 27} = 2.4 \text{ cu. yd.}$$

In the rectangle O we have $F - C = 21.9$, and $C = 2.4$; whence $F = 21.9 + 2.4 = 24.3$ cu. yd. The total fill for the entire tract is

$$1.9 + .3 + 24.3 = 26.5 \text{ cu. yd.} \quad \text{Ans.}$$

52. Quantities in Street Grading.—The earthwork to be moved in street grading is usually best measured by

taking cross-sections of the street as often as needed, determining the areas of those sections, and applying either the prismoidal formula or the average end-area method. The street cross-profile will be a standard form, such as is shown

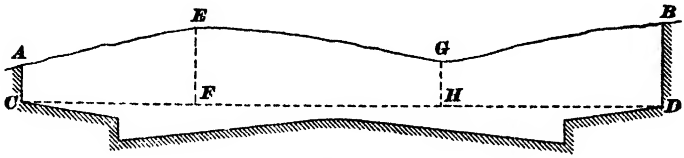


FIG. 18

in Fig. 18; the area below the line CD, which will be common to all sections, may be computed once for all, the area remaining to be computed being $ACFHDBGEA$. In the field, levels would be taken at A, E, G, and B, from which, and the known grade elevations, the heights AC, EF, GH, and BD could be obtained. Some engineers advocate the use of the planimeter for computing the area, but it is doubtful whether this is wise—unless the sections must be carefully plotted to scale for some other reason—as the computations can be made almost if not quite in the time taken to plot the sections. The trapezoidal rule or Simpson's rule can be used for these computations (see *Plane Trigonometry*,

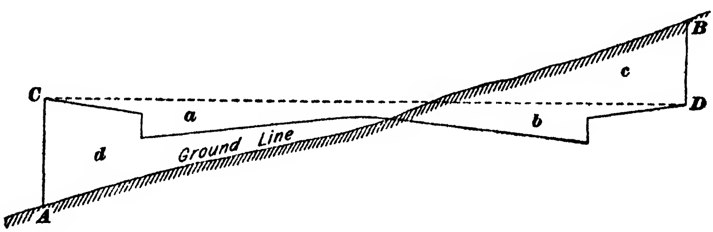


FIG. 19

Part 2). In side-hill work (see Fig. 19), it may be best to use the planimeter, measuring the cut and fill areas separately. The volume is calculated as explained in *Earthwork*.

MONUMENTS AND BENCH MARKS

MONUMENTS

53. Purpose of Monuments.—Monuments in a city may be for one of two purposes; namely, the determination of elevations, or the location of lines. Those used for elevations are called **bench marks**, and those used for the location of lines, simply **monuments**.

54. Necessity for Line Monuments.—That permanent monuments to mark the street or block lines in a city are an absolute necessity seems almost to go without saying; yet, in almost all cities, the original marks defining the street or block lines have long since disappeared, and the lines have been perpetuated by buildings supposed to have been placed on the lines. Had the buildings been so placed, the destruction of the monuments would not have been so serious a matter, but, as a rule, they have not been correctly placed. Often the best that can be done is to average up the lines indicated by various buildings or fences known to have been intended to be on the lines sought. In many of the older larger cities, these lines have become well fixed by the years of repeated locations, but in many newer cities and additions the practice is still to place a wooden stake at the block corners, to be removed when the fence posts or the building is begun. It would be an exceedingly wise thing for every city to have permanent monuments set to mark every street line now unmonumented, and to require the setting of such monuments in all new tracts in which streets are offered to the public. If permanent indestructible monuments do not exist, each surveyor, in his endeavor to arrive at the truth, will interpret the existing lines according to his knowledge, in all probability choosing, as most correctly representing the lines, buildings or fences different from those taken by his predecessors, with the result that the offsets and irregularities frequently lead to costly litigation.

55. Materials for Monuments.—Wooden stakes have been most generally used for the first monuments of a subdivided tract. They last a few years, perhaps five in good soil, and longer when made of cedar or redwood; they are cheap, and easily centered with a tack; but they are also easily moved by the action of frost, and are altogether unsuitable for permanent monuments. Iron pins have been much used and serve very well for a few years; but are also easily disturbed by frost, and in a country with cold winters do not make good permanent monuments. Iron monuments are easily found by using a magnetic-compass needle in the immediate vicinity of the pin. They last many years longer if of cast iron than if of wrought iron.

Satisfactory monuments have been made of fireclay, or shale, 2 feet long and 4 inches in diameter. An excellent monument is made by boring with a post-hole auger about 2 to 4 feet into the ground and filling the hole with cement mortar composed of from two parts of sand to one of cement to four of sand to one of cement. The monument may be centered while yet soft by placing in it at the proper point a copper bolt whose head contains a graven or stamped cross.

Probably the best monument is one of granite, about 6 inches square on top, larger at the bottom than at the top, dressed down from the top on four sides for about 6 inches, with a copper bolt set and leaded into a hole drilled in the top. The stone should be 3 or more feet long, and should be set below the depth of frost. A temporary gas pipe or other tube may reach from the mark on the top of the monument to the surface of the ground, or a cast-iron box similar to a manhole cover may be used to keep a space open to the stone.

A crow's-foot mark on a curb is often used as a monument. This is a very cheap and convenient form of monument, but is likely to be disturbed in repairing the street or sidewalk, and may even be removed with the curbstone.

56. Position of Line Monuments.—Three general positions are chosen for line monuments; namely, (1) the

intersection of street center lines; (2) the block corners; (3) a point at some arbitrary distance from either the center lines or the property lines. The difficulty with the center-line intersection is that sewers are usually in the center of the street, and necessitate deep openings that disturb the monument. Water and gas pipes and steam and electric conduits lie on each side of the center of the street, buildings occupy the block corner, and in the business district the areas under the sidewalks are used for vaults, coal bins, etc. Paving operations covering the entire street, street-car tracks and conduits, and other constructions make it almost impossible to find a permanent spot for a monument. It is probable that, in residence districts, monuments set at small offsets, $1\frac{1}{2}$ to 5 feet from the property lines, are most favorably located; while, in business districts, perhaps the best monument is a mark on the curb. It will be disturbed, to be sure, from time to time, but not frequently, and if properly protected by ordinance, and properly referenced, it can always be recovered with ease, and it is in the least obstructed part of the street area in a large and busy city. The mark should be placed at an offset from the property lines, as shown at *m* in Fig. 20, to permit ranging with the transit. The offset should be uniform throughout the city.

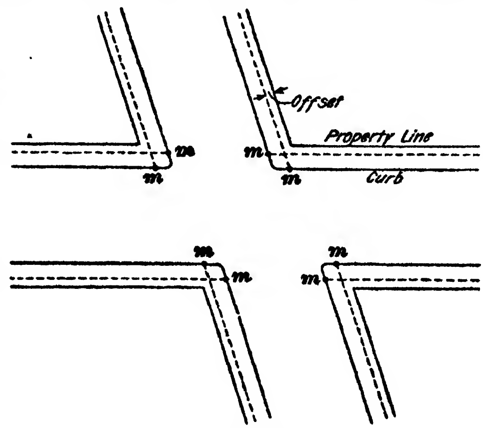


FIG. 20

57. Witnessing of Monuments.—All monuments should be *witnessed* by making and recording measurements to near-by objects of reasonable permanence. While the monuments are supposed to be permanent, they may be

disturbed, and, being sometimes covered, the witness measurements assist in finding them. A sufficient number of witnesses should be secured to allow for the destruction of one or more. If permanent objects do not exist near a monument, auxiliary monuments may be set above the ground, and measurements taken to them. Such monuments are called **witness monuments.** The measurements are not usually made with sufficient precision to relocate the exact center point of the monument, and hence are not reliable for replacing exactly an obliterated or lost monument. They should, however, be sufficiently accurate to relocate from witness points the monument close to its former position. When a monument is to be disturbed for street improvements, it should be *exactly* referenced, preferably by cross-lines to temporary points not to be disturbed during the improvements, and replaced as soon as the ground will permit. If the reference points can be set close to the monument, the best way is to stretch two fine strings across the monument, with their intersection on or over the center of the monument and their ends on the witness points selected. If the witness points must be at some distance—say 25 or 30 feet or more—the transit may be set over one witness point, ranged on the monument, and a second witness set in this line produced; the transit will then be set on a third witness to one side of the line just ranged, turned on the monument, and a fourth point set in the line prolonged. After the work that has disturbed the monument is complete and the ground has been properly settled, a reversal of the operation will fix the monument again. The method is to set on the first witness point, range on the second, and set two points close to and on opposite sides of the approximately known position of the monument; then, stretching a string over these two points, set the transit on the third point, range on the fourth, and find a point in this line on the string. This will be the center of the disturbed monument.

BENCH MARKS

58. Character and Location of Bench Marks. Bench marks are permanent objects—such as points on the water-table or other projection of permanent buildings—whose elevations above a plane or surface, known as the **city base, city datum,** or simply **the base,** are known. The elevations are determined by leveling from a primary bench mark, whose elevation above the city datum may either be obtained by leveling, if that datum is a natural existing surface, as mean sea level, or be assumed, if the datum or base is an arbitrary surface considered as being so many hundred feet below the primary bench mark. The latter condition usually obtains in inland towns, although efforts are frequently made to have the base approximate the level of the sea, assuming the primary bench mark to be the round hundred of feet nearest to its supposed or known elevation above sea level. In cities on the coast, it is usually desirable to have the city base below mean tide, perhaps 100 feet, in order that elevations taken in excavations that may extend below tide water may not be negative.

The bench marks for a city should be well distributed, so that leveling operations for grading or building in any part of the city may start from a near-by bench mark. They should all be consistent, so that work begun from one bench mark may be checked on another.

59. Determining and Adjusting Elevations of Bench Marks.—The elevations of the bench marks of a city, determined by leveling from the primary bench and from other secondary benches, will be more or less inconsistent unless they are carefully adjusted. This adjustment should always be performed. The following illustration will indicate the general method of procedure: Suppose P, Fig. 21, to be the primary bench, the other lettered corners being secondary benches distributed over the city. If the elevations of these benches are consistent, it is evident that, if the difference in

level between A and B, that between B and C, that between C and F, and that between F and A are added algebraically, the sum should be zero. Thus, suppose the several corners to have the following actual elevations: A, 426.421; B, 447.632; C, 450.964; F, 439.672; then, the differences are

$$\begin{aligned} A \text{ to } B,\ 447.632 - 426.421 &= +\ 21.211 \\ B \text{ to } C,\ 450.964 - 447.632 &= +\ \ 3.332 \\ C \text{ to } F,\ 439.672 - 450.964 &= -\ 11.292 \\ F \text{ to } A,\ 426.421 - 439.672 &= -\ 13.251 \\ \text{Sum} &= \ \ 00.000 \end{aligned}$$

But suppose that, in leveling around the polygon, the differences found are the following:

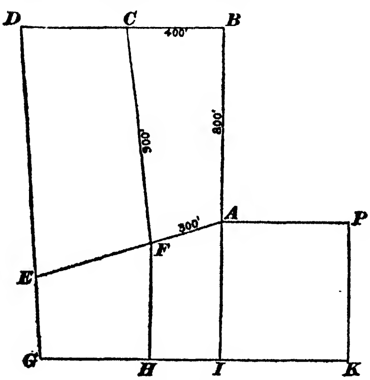


Fig. 21

$$\begin{aligned} A \text{ to } B,&\ +\ 21.200 \\ B \text{ to } C,&\ +\ \ 3.342 \\ C \text{ to } F,&\ -\ 11.271 \\ F \text{ to } A,&\ -\ 13.252 \\ \text{Sum} =&\ +\ \ 0.019 \end{aligned}$$

Then, if the elevations B, C, and F are determined in order from A, by using these differences, the level of A, determined from F, will differ by .019 from that used to begin with. Similarly, the elevations of the corners of each polygon must be consistent, but will not be so ordinarily, because each is obtained by applying the difference in level between it and its adjacent corners. This error of closure, as it may be called, must be distributed among the several sides so that each polygon shall be consistent. This is called **adjusting the polygon.** There are elaborate methods of adjusting the whole series at once by the use of the method of least squares, but the work is complicated and laborious, and simpler methods produce results of sufficient precision.

60. It may be assumed either that the errors that have been made are proportional to the distances between adjacent

benches, or that they are proportional to the square roots of those distances. The late Prof. J. B. Johnson, who was an authority on precise leveling, advised the square root, which seems to agree better with practical considerations. When a whole system of several polygons is to be adjusted, that one containing the largest error is adjusted first, that containing the next largest error second, and so on. When one or more sides of a polygon to be adjusted are also sides of polygons already adjusted, the adjusted values of those sides are not changed, but the whole error is distributed among the remaining unadjusted sides. Care should be taken in this method that an interior polygon entirely surrounded by other polygons is not the last to be adjusted, as the method may then fail.

The polygon *ABCF*, Fig. 21, is adjusted as indicated in the following table:

Length of Sides	Square Roots of Lengths	Total Error	Proportion	Original Difference	Corrected Difference
AB, 800	28.28		$\frac{.019}{95.60}\times 28.28 = -.006$	+ 21.200	+21.194
BC, 400	20.00		$\frac{.019}{95.60}\times 20.00 = -.004$	+ 3.342	+ 3.338
CF, 900	30.00	.019	$\frac{.019}{95.60}\times 30.00 = +.006$	− 11.271	−11.277
FA, 300	17.32		$\frac{.019}{95.60}\times 17.32 = +.003$	− 13.252	−13.255
	95.60			+ .019	0.000

The square roots of the lengths are first obtained. The total error is divided by the sum of these roots, and the correction for each difference is found by multiplying the quotient thus obtained by the square root of the corresponding length.

Since the plus differences were too large, they must be diminished, while the minus differences must be increased. Beginning now with the elevation of point *A*, the other points may be determined in either direction around the polygon.

The elevations that result are as follows, assuming that of A to be 426.421:

$$\begin{aligned}
A &= 426.421 \\
&\ \underline{21.194} \\
B &= 447.615 \\
&\ \ \ \underline{3.338} \\
C &= 450.953 \\
&\ \underline{11.277} \\
F &= 439.676
\end{aligned}$$

It will be observed that these are not the elevations first assumed to be correct, and it is true that they are probably not the true precise elevations, but they are as near to the truth as the nature of the work permits.

In determining the error in the polygon $CDEF$, the corrected difference for the side CF would be used, and the whole error distributed among the three remaining sides.

OFFICE RECORDS

61. Block Books.—For land lines, perhaps the best form of record book is a **block book**, which is large enough to have a single city block drawn on a page, to a scale of from 50 feet to 100 feet to the inch. All records of distances, angles, monuments, etc. obtained from lot or street surveys can be easily shown on the plot in the book. With each block should be shown the relation of its lines to those of the adjoining blocks. The book should be indexed, and should be arranged in some logical order, preferably in some other manner than by wards, which, being political divisions, are subject to change. The blocks may be arranged from south to north or from north to south, and from west to east. This is a good arrangement, since maps of adjoining property will be close together in the book for more convenient reference. The index may be arranged alphabetically by tract or addition, or by some other scheme fitting the conditions in the particular city in which the surveyor works.

These block books are sometimes large, like an atlas, and contain the map of a whole tract or addition on a single page

or on two pages. This has the advantage of showing at a glance the relations of a considerable number of lines; and, as each tract or addition usually has some peculiarities of its own, they appear more clearly on a map of the whole addition showing the relations of street lines outside the addition to those within it.

62. Block Cards.—An excellent system for recording land-line measurements is the card system. A standard filing or index card, 5 in. × 8 in., which is a stock size, is large enough to map most single blocks, and to show the several measurements that may be made from time to time. Such a lot of cards should be arranged logically in the same order as would be used in a block book, and a separate drawer of ordinary cards, 3 in. × 5 in., should be used to index the map or block cards. In a busy office, these cards have the advantage of permitting several persons to work on different blocks at the same time, and they are more readily handled on a desk or table than is a book. By consulting the catalog of any of the filing-cabinet makers, the surveyor will be able to select a suitable set of cards for his purpose.

63. Record Maps.—Copies should be made of the record maps of subdivisions of the various plots, tracts, or additions filed in the office of the custodian of records. These copies should be on tracing cloth, and should be exact copies of everything appearing on the original maps. In a newly established office, the making of these plots should be one of the first duties occupying all the spare time of the office force. The copies need not be of the same size as the original plots, but should rather be of uniform size for convenience in filing. A size governed by the size of local plots, and a scale large enough to permit the clear showing of all dimensions, angles, numbers, etc. should be adopted. These tracing-cloth copies should be filed for record, prints being made on tough thin paper for office and field use. Prints may also be made as wanted for sale to interested persons, such as real-estate dealers, abstract makers, etc. These record maps may be filed in drawers in a filing

cabinet. They should all be numbered with the year of the subdivision record and a serial number; thus, 1896–2, 1896–3, etc. The names of the years covered by the maps may appear on the outside of the drawers containing them. The index, which should be by name of parcel, plot, tract, or addition, would give the year and serial number of the plot, thus insuring its quick location. Or, the drawers may simply be numbered, in which case the index will give the drawer and map number.

The title of the drawings and all lettering should be uniform in size and style. It is not necessary that the plots contain all references and tie-lines to locate corners or monuments, as these will appear in the field books or in the monument books devoted to this purpose.

From time to time, as surveys of lots are made, the date and number of survey may be written in the lot space on the plot.

64. Filing of Maps and Profiles.—Of necessity, continuous profiles of long lines must be rolled, but it is much better to make shorter lengths on sheets that can be filed flat. Moreover, maps to be used for reference, as well as all drawings of plans, should be on sheets of standard size. To get the best results, sheets for filing purposes should be of such a size that they can readily be cut into halves, quarters, etc., without waste, in case smaller cards are desired; and these standard sizes should be strictly adhered to. Thus, a sheet 24 in. × 36 in. will cut into sheets 18 in. × 24 in., 12 in. × 18 in., 9 in. × 12 in., and 6 in. × 9 in., all of which are good filing sizes. Drawing paper 24 in. × 36 in. is made, and is used by many large construction companies, but it is not the commonest size, nor does it fit the drawers of the various filing cabinets now made. Other sizes may be used, or special cabinets may be built for drawings. The drawers should be about $1\frac{1}{2}$ to 2 inches larger in both directions than the sheets to be filed, and from $1\frac{1}{2}$ to 2 inches deep. Drawers deeper than this will hold too many drawings to be conveniently handled in looking for any particular set. Each

drawer should be numbered or lettered, as well as each stack or case; if the drawer is numbered, the stack or case should be lettered, and vice versa.

Profiles that are rolled are perhaps best kept in numbered cylindrical cases with covers. The number is painted on the end, and the cases are filed in racks, with compartments large enough for one or two dozen cases; or they may be filed in drawers made to fit them.

Maps for recording purposes should be on tracing cloth, from which blue or positive prints on tough paper may be made for office and field use.

Alterations, as they are made in the lines represented on any map, may also be put on the tracing and new prints made, when the old ones should be discarded.

65. Private Surveys.—Every survey for an individual, no matter how small or insignificant the survey may be, should have its complete record carefully kept and indexed. Each survey should have a serial number. The notes should always be taken in a field book, never on a scrap of paper, and these notes should bear the date and number of the survey, the names of the surveyor and his assistants, a brief record of any pertinent conversation held concerning the survey, the time of day, and the general condition of the weather, besides the usual notes of measurement for angles, tie-lines, etc. Many such notes seem trivial in the extreme, and some of them are never seen a second time, but occasionally unexpected litigation arises that makes them of the greatest value to the surveyor acting as an expert witness. Their value at such times will frequently, for even a single court case, far exceed the cost of making complete notes for all the surveys of a whole year. The index of the notes should be double, under the owner's name or the name of the person for whom the survey is made, and again under the block, tract, addition, or street number or name.

66. Field Books.—In the field book, the notes of more than one survey or measurement should never appear on one page. The notes of a single survey or series of measure-

ments for a single purpose may extend over several pages, but many surveys are exceedingly simple; as, for instance, the measurement of the distance from a saloon to a church or school in an excise case, the measurement of the height of a dam, a wall, the dimensions of a cross-walk, the length of a private sewer, or the like, which might require one or two lines only of a book, or might be considered to be so trivial as to make a written note of the work superfluous. Nevertheless, the notes of any such measurements should be given a separate page in the notebook, when the miscellaneous notes of weather, assistant, date, hour, etc. will occupy more space than the simple memorandum of the work done. The field book should be indexed on one or two of the back or front pages; while a simple table of contents should be entered as the notes are taken, and a separate alphabetical index made when the book is full.

67. Card Index.—A card index should be kept of all records of surveys, and of all maps or drawings in the surveyor's office. The index should be by streets, blocks, tracts, additions, sections, or other land division—never by political divisions. The card index may be divided into sections; such as, private surveys, street surveys and maps, sewer surveys and maps, waterworks surveys and maps, etc. If there are field notes, a profile and a map of a given survey—such, for example, as a street survey—all these should appear on the proper index card, which should indicate the number and page of the field book, the number and drawer or compartment or case of the profile or map, and the date of the particular survey under consideration. Each surveyor will devise a scheme of indexing adapted to his needs.

68. Monument Records.—In the office there should be several bench-mark books containing a list of the bench marks in the city, with their elevations and a description of the marks so clearly written that any one may find them. Any party in the field should have with it a bench-mark book. The list should be put in the book by streets, for ready reference. Similarly, there should be several books

of street-line monuments, showing by streets all monuments and all reference or tie-lines to them. Both bench-mark and monument books should be ordinary field books of the same type as used for the field surveys, numbered on the backs, and should contain on their front pages a table of streets whose monuments or bench marks are shown. A card index by streets giving references to the bench-mark and monument books will be found convenient.

69. Cost.—The record of cost should include the time consumed in each survey. Each piece of private work that comes into the office should be entered on an order card, which is kept in its proper place in a file used for work in progress. On the face of this card should appear the date of the order, the name of the person ordering, for whom the order is made, and the date of completion of the work and of sending a report, and on the back should appear a complete time account of every man working on the particular commission, whether in field or office. From this time account the cost of the survey may be determined. The order card should be filed for reference when the work is completed. The cards for every year may be filed together in chronological order; the card index to the survey indicating the date will enable a cost card to be quickly found.

Besides these card files, a regular set of books should be kept, as in any other business.

70. Remarks on the Keeping of Records. — It requires no little time to keep complete and systematic records, but the time is more than saved when the information so carefully indexed is wanted. It is particularly desirable that a young surveyor beginning an independent practice should take the time to make full records under some well-devised system. He will be likely to neglect this while his work is light and seemingly unimportant. He should avoid this tendency and remember that none of his work is unimportant, and that each piece will sooner or later have some bearing on some subsequent work.

CITY STREETS

THE ROADWAY

1. Introductory.—The width of city streets has been considered in *City Surveying*, and paving has been treated in *Pavements*. This Section will deal with the form of the roadway; the form, position, and construction of curbs and footways; and the subject of street grades.

2. Parts of a City Street.—A city street is made up of the **roadway** for vehicles; the **sidewalk** or **footway** for pedestrians; the **curb**, marking the line between roadway and footway and protecting the latter from vehicular encroachment; and, in residence districts, the street **lawn** adjacent to the footway either between the sidewalk and curb, or between the sidewalk and property line, or in the middle of the street, dividing the roadway into two parts and forming a parkway; or in all three parts of the street width.

WIDTH AND CROSS-SECTION OF ROADWAY

3. Width.—The total width of a street will not necessarily be wholly occupied by the pavements. Indeed, except in important business thoroughfares, it is seldom that the entire width of the street is occupied by the roadway and sidewalks. As the widths of these can be easily changed whenever the pavement is renewed, they should always correspond with the immediate requirements of the traffic passing over them. The widths should always be sufficient to easily accommodate the traffic, but widths materially greater than this are disadvantageous.

The roadway should be of such width that it will all be used. The width necessary to accommodate the traffic depends on the volume and character of the latter. A width of 80 feet will usually be sufficient for the roadway of a crowded commercial thoroughfare in a large city, while a width of 60 feet will accommodate the traffic of a very important business street. For many business streets, a width of 50 feet will be ample for the roadway, while for others a width of 40 feet will be sufficient. For residence streets, the width of roadway should generally be from 24 to 36 feet, according to the importance of the street and its position with reference to the routes of greatest travel. The widths of the roadways on the important residence streets of an American city of about 100,000 inhabitants are being reduced, as the streets are paved, from 34 to 30 feet: the former width having been found to be greater than is required, considerable saving in the cost of paving and maintenance is effected by reducing the width. When no portion of the roadway is occupied by street-railway tracks, a width of 24 feet will accommodate a very considerable amount of light driving, and will be sufficient for many residence streets not situated along the main lines of travel. Even less width will sometimes be sufficient for roadways in small towns and villages. On streets of light traffic, the roadway should be narrowed to the width really required; this will permit the roadway to be much better improved than would be possible with a wider roadway with the funds available. Moreover, weeds will not then grow in the unused portion of the roadway.

4. Cross-Section.—It is necessary to provide gutters or side ditches along the outer edges of the roadway to carry away the surface water; and, in order that the water falling on the surface of the roadway may be thrown off into the side gutters, the center of the roadway must be made higher than the outer edges. The form of cross-section that will best satisfy these conditions depends chiefly on the character of the roadway surface and on the nature of the traffic.

Until such time as a roadway is paved, its cross-section will have a more or less irregular form, and will but roughly approximate any theoretical figure. Unpaved roadways, however, are generally so laid out and graded as to more or less closely approximate some theoretical form of cross-section. When a street is paved, it is given a definite cross-section, the form of which depends on the kind of pavement, the grade of the roadway, the nature of the traffic, and the ideas of the engineer in charge of the work. Some kind of gutter is always provided along each outer edge of the roadway, and the roadway between the gutters is raised. The roadway is then said to be **crowned**, and the term **crown** is applied both to the whole cross-section and to its highest point.

CROWN

5. Height of Crown.—The height of the crown above a straight line through the outer edges of the roadway, or bottoms of the gutters, will here be designated the **height of crown.** The height of crown necessary to efficiently throw off the surface water into the side gutters and at the same time cause no inconvenience to the traffic depends chiefly on the character of the roadway surface and its grade. The crown or lateral slope of the roadway should never be so great as to produce inconvenient tipping of vehicles in driving on the side of the roadway, as this will cause the traffic to follow the center of the roadway, thereby rapidly wearing away that portion and destroying the crown. The more smooth and perfect the roadway surface, the more easily will the water flow off, and, consequently, the less will it need to be crowned. Well-paved streets will require considerably less height of crown than ordinary earth roads.

For paved roadways, the height of crown, and, therefore, the lateral slope, should be less on steep than on flat or level grades. This will make the roadway surface somewhat less slippery and inconvenient for travel on steep grades, while there will generally be no difficulty about the water reaching the gutters without damage to the roadway, if it is paved.

On the other hand, for an earth or gravel roadway likely to become damaged by the water following the roadway and washing out gulleys and channels in flowing down steep inclines, the height of crown of the roadway should be increased on steep grades, in order to more quickly throw off the water into the side gutters and as far as possible prevent it from flowing down the roadway. In spite of such precaution, however, if the roadway is not constantly kept in good repair, water will flow along in the wheel ruts and in the depressions worn by the horses' feet, and do more or less damage on steep inclines.

6. Height of Crown for Light Grades.—It is impossible to express accurately in mathematical language the conditions just stated. Hence, no really satisfactory formula

TABLE I

VALUES OF COEFFICIENT q RELATING TO THE CROWN OF ROADWAYS

Character of Roadway	Value of q
Common earth roadways	$\frac{1}{40}$
Ordinary gravel roadways	$\frac{1}{50}$
Broken-stone roadways	$\frac{1}{60}$
Wooden-block pavement	$\frac{1}{70}$
Cobblestone pavement	$\frac{1}{80}$
Granite-block pavement	$\frac{1}{90}$
Well-laid brick pavement	$\frac{1}{100}$
First-class asphalt pavement	$\frac{1}{120}$

for the height of crown can be given. As, however, the height of crown should usually be proportional to the width of the roadway, a formula for a comparatively level grade may be written as follows:

$$c = q\,w$$

in which c = height of crown, in feet;
w = width of roadway, in feet;
q = a coefficient relating to the character and condition of the roadway surface.

While no exact values can be given for q, those given in Table I may be taken as fairly approximate averages.

It must be understood that the values given in Table I are merely approximate. In actual practice, they can generally be more or less varied to advantage, and should usually be somewhat modified. Narrow roadways may generally be given a somewhat greater crown proportionately than wide roadways.

7. General Formula for Height of Crown.—Where the roadway is on any considerable grade, the following general formula may be used for the height of crown:

$$c = q\,w + \frac{w\,p\,(70\,q - 1)}{800}.$$

In this formula, c, q, and w have the same meaning as in Art. **6**, and p is the per cent. of grade, or number of feet rise or fall in 100 feet horizontal length of roadway.

EXAMPLE 1.—A common earth roadway 24 feet wide has a grade of 5 per cent.; what height of crown should it have?

SOLUTION.—As given in Table I, the value of q for a common earth roadway is $\frac{1}{40}$. By applying the formula in this article and using this value of q, we have,

$$c = \frac{24}{40} + \frac{24 \times 5 \times (\frac{70}{40} - 1)}{800} = .7125 \text{ ft.} \quad \text{Ans.}$$

EXAMPLE 2.—A roadway 48 feet wide, paved with asphalt, has a grade of 1.44 per cent.; what height of crown should it have?

SOLUTION.—By applying the formula of this article and using the value of q as given for asphalt in Table I, we have,

$$c = \frac{48}{120} + \frac{48 \times 1.44 \times (\frac{70}{120} - 1)}{800} = .364 \text{ ft.} \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE

1. A roadway 35 feet wide, paved with wooden blocks, has a grade of 6 per cent.; what height of crown should it have? Ans. .50 ft.

2. An ordinary gravel roadway 20 feet wide has a grade of 4 per cent.; what height of crown should it have? Ans. .44 ft.

3. A roadway 60 feet wide, paved with brick, has a grade of 2 per cent.; what height of crown should it have? Ans. .555 ft.

4. A common earth roadway 16 feet wide has a grade of 9 per cent.; what height of crown should it have? Ans. .535 ft.

8. Form of Crown.—With reference to the manner in which the roadway is crowned, two forms of cross-section are advocated and used. In one form, the surface line of the cross-section is the arc of a circle or of some other curve, usually a parabola. This form of cross-section is shown in

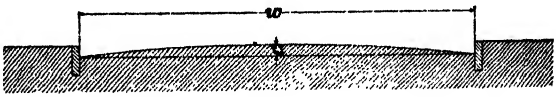


FIG. 1

Fig. 1, and will here be called a **curving crown.** As will be noticed in the figure, the roadway surface has a much greater lateral slope near the outer edges than it has near the center. The effect of this is to cause the greater part of the traffic to follow the center of the roadway, producing the greatest wear on that part.

In the other form of cross-section, the surface line consists of two straight lines having the proper inclination and connected by a short curve at the center of the roadway, as shown in Fig. 2. The length of the curve at the center is usually

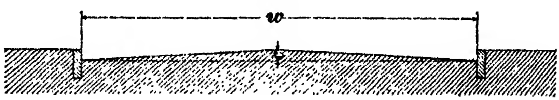


FIG. 2

made about 5 feet, or a little more than the width of an ordinary carriage. In this form of cross-section, which will be called a **sloping crown,** the lateral slope of each side of the roadway extends uniform to the gutter, and the width of the nearly level portion at the center is greatly reduced. This insures a more efficient drainage and at the same time permits teams to drive close to the curbing with nearly as much comfort as on any other portion of the roadway.

9. Elevations on Cross-Section.—In laying out the cross-section of a roadway, it is necessary to determine the elevations of the surface at different points across the roadway. In almost all cases, whether the roadways have curving or sloping crowns, the summit of the crown is at the

center of the roadway, and the slopes of the sides are symmetrical with reference to the center. Such a crown will here be called a **symmetrical crown.** In this and the following two articles, only symmetrical crowns are considered.

The grade line of a roadway represents the elevation of the summit of the crown. Consequently, for any cross-section having a symmetrical crown, the elevation of the roadway surface at the center is given directly by the grade line, and the elevation of any other point in the surface of the cross-section must be referred to the elevation of grade. The elevation of any point in the surface of the cross-section, other than the center or summit, must be determined by its distance below the grade line. The distance of any point in the surface of the cross-section below the grade line or summit of the crown may be easily determined by means of the rectangular coordinates of the point, taking the origin at the summit of the crown.

10. Coordinates to Curving Crown.—For a cross-section having a curved surface line, as shown in Fig. 1, a good form is given by a circular curve. The equation of the

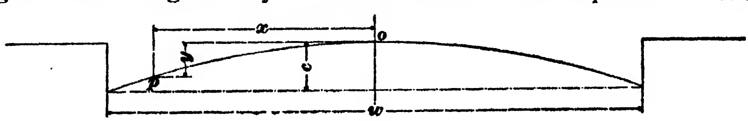


FIG. 3

curve, however, will be somewhat simpler for a parabolic than for a circular curve, and as, for so flat an arc, the two curves will be practically identical, the parabolic curve will be used. With this curve, if x and y are, respectively, the abscissa and the ordinate to any point p in the surface line of the cross-section, with the origin at the center o, as shown in Fig. 3, the value of y for any corresponding value of x, or, in other words, the distance of the given point below a horizontal line tangent to the roadway surface at the center, will be given by the formula (see *Rudiments of Analytic Geometry*)

$$y = \frac{4 c x^2}{w^2}$$

11. Coordinates to Sloping Crown.—A cross-section having a symmetrical sloping crown is shown in Fig. 4, the height of crown being somewhat exaggerated. In this figure, as in Fig. 3, c and w are, respectively, the height of crown and the width of roadway, while x and y are the abscissa and the ordinate, respectively, of any point p in the surface line of the cross-section, with reference to an origin at the center o of the roadway. The two portions tg and $t'g'$ of the surface line of the cross-section have a uniform slope, while the portion tt', whose width is denoted by b, is a short parabolic curve joining the two slope lines and tangent to them.

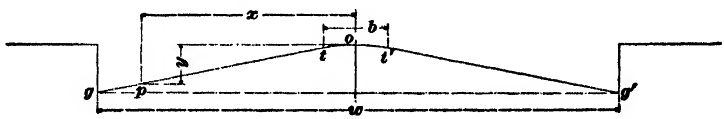


FIG. 4

The rate of lateral slope for the uniformly sloping portions gt and $g't'$ is given by the formula

$$s = \frac{4c}{2w - b} \qquad (1)$$

in which s is the rate of slope, or vertical fall in each foot horizontal.

The coordinates x_c and y_c of any point on the curved part of the cross-section are related by the formula

$$y_c = \frac{s x_c^2}{b} \qquad (2)$$

At the tangent point t, where the curved part of the surface line joins the straight part, the abscissa x_c will have the value $\frac{b}{2}$; by substituting this value for x_c in formula **2**, and reducing, the following value is found for the ordinate y_t at the tangent point t,

$$y_t = \frac{sb}{4} \qquad (3)$$

The coordinates to any point p along the straight slope line tg are related by the formula

$$y = s\left(x - \frac{b}{4}\right) \qquad (4)$$

EXAMPLE 1.—If the roadway described in example 1 of Art. **7** is given the height of crown there determined, in the form of a curving crown, what will be the ordinate to a point in the surface line of the cross-section distant 8 feet from the center of the roadway?

SOLUTION.—The width of the roadway, as given in the example referred to, is 24 ft., and the height of crown is .7125 ft.; the abscissa x, or the distance of the given point from the center of the roadway, is 8 ft. By the formula of Art. **10**, which applies to curving crowns, the value of the ordinate y is found to be

$$\frac{4 \times .7125 \times 8^2}{24^2} = .3167 \text{ ft., very nearly. Ans.}$$

EXAMPLE 2.—If the roadway described in example 2 of Art. **7** is given the height of crown there determined, in the form of a sloping crown, what will be the ordinate to a point in the surface line of the cross-section 15 feet from the center of the roadway, assuming the length b of the central curve to be 5 feet?

SOLUTION.—The width of the roadway, as given in the example referred to, is 48 ft., and the crown is .364 ft.; the abscissa x, or the distance of the given point from the center of the roadway, is 15 ft., and the length b of the central curve is 5 ft. By applying formula **1**, the rate of slope s in the uniformly sloping portion of the cross-section is found to be $\frac{4 \times .364}{2 \times 48 - 5} = .016$ ft. per horizontal foot. By applying formula **4**, the value of the ordinate to a point in the roadway surface 15 feet from the center is found to be $.016\left(15 - \frac{5}{4}\right) = .22$ ft. Ans.

EXAMPLES FOR PRACTICE

NOTE.—The following examples relate to the Examples for Practice given at the end of Art. **7**. In each case, the width of roadway and amount of crown will be taken as given in the corresponding example of the article. The results will not be carried beyond the fourth decimal place.

1. If the roadway of example 1 is given a curving crown, what will be the values of the ordinates to the surface line at points in the cross-section distant from the center: (*a*) 2.5 feet? (*b*) 5 feet? (*c*) 10 feet? (*d*) 15 feet? (*e*) 17.5 feet?

$$\text{Ans.}\begin{cases} (a)\ .0102 \text{ ft.} \\ (b)\ .0408 \text{ ft.} \\ (c)\ .1633 \text{ ft.} \\ (d)\ .3673 \text{ ft.} \\ (e)\ .5 \text{ ft.} \end{cases}$$

2. If the roadway of example 2 is given a sloping crown, with a central curve 8 feet in length, what will be the values of the ordinates to the surface line of the cross-section at points distant from the center:

(*a*) 4 feet? (*b*) 8 feet? (*c*) 10 feet? (*d*) What will be the rate *s* of the uniform side slope?

Ans. (*a*) .11 ft. (*b*) .33 ft. (*c*) .44 ft. (*d*) .055 ft.

3. If the roadway of example 3 is given a sloping crown, with a central curve 9 feet in length, what will be the ordinates to the surface line of the cross-section at points distant from the center: (*a*) 3 feet? (*b*) 4.5 feet? (*c*) 10 feet? (*d*) 15 feet? (*e*) 20 feet? (*f*) 25 feet? (*g*) What will be the rate *s* of the uniform side slope?

Ans. (*a*) .02 ft. (*b*) .045 ft. (*c*) .155 ft. (*d*) .255 ft. (*e*) .355 ft. (*f*) .455 ft. (*g*) .02 ft.

4. If the roadway of example 4 is given a curving crown, what will be the ordinates to the surface line of the cross-section at points distant from the center: (*a*) 4 feet? (*b*) 8 feet?

Ans. (*a*) .1338 ft. (*b*) .535 ft.

GUTTERS AND CURBS

GENERAL FORM AND POSITION

12. Gutters.—As has been previously stated, some kind of open channel must be provided along each side of a roadway, to receive the water from the surface and convey it to a drainage outlet. Deep side ditches, such as are used on country roads, would be unsightly, dangerous, and otherwise impracticable for a city. Surface drainage in city streets is accomplished by forming those parts of the roadway adjacent to each outer edge to serve as gutters for conveying the water from the surface These gutters are made so shallow as to be available, to some extent, for driving purposes when not required for drainage.

13. Forms of Gutter.—Various forms of gutter are used; of these, the three shown in Figs. 5, 6, and 7 are the most common. The form shown in Fig. 5 is the simplest and, all things considered, probably the most advantageous

for well-paved roadways. It is very commonly used with the best pavements. In this form, the crown of the roadway is continued regularly to the curb line, the gutter being formed by the angle between the sloping surface of the roadway and the vertical side of the curbing. The full width of the roadway is thus left available and convenient for driving.

FIG. 5

The form of roadway shown in Fig. 6 is the same as that shown in Fig. 5, except that the bottom *g* of the gutter is made level. Little, if any, advantage is gained, however, by this method of treatment, and this form of gutter is not in general so good, nor nearly so extensively used, as the form shown in Fig. 5. Where the gutters are paved with

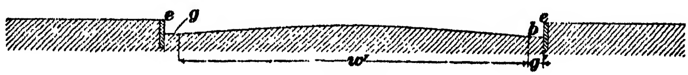


FIG. 6

cobblestone, the form shown in Fig. 7 is very commonly employed. When a substantial stone curbing is used, it is doubtful whether any advantage is gained by this form of gutter, while it possesses the disadvantage of narrowing the available driveway *w'*, and also of making it inconvenient for carriages to drive close to the curbing.

14. Width of Gutter and Crown.—In Figs. 6 and 7,

FIG. 7

w' is the width of the crowned portion of the roadway, or width between gutters, and *g* and *g'* are the widths of the two gutters. The width of the gutter is sometimes made equal to the height of the crown, although commonly gutters are made considerably wider. It is evident that, for gutters of the forms shown in Figs. 6 and 7, the crowned width *w'*

of the roadway will be equal to the total width of the roadway minus the width of the two gutters, or—when the width of the gutter is made equal to the height of the crown—minus twice the height of the crown.

In applying the formula of Art. **7** for determining the height of crown in roadways having gutters like those shown in Figs. 6 and 7, the full width of the roadway between curbing may be substituted for w; but in applying the formula of Art. **10,** or formula **4** of Art. **11,** for obtaining the ordinate at the gutter, the abscissa x should be taken equal only to one-half the crowned width, or $\frac{w'}{2}$.

15. Curbing.—Flat stones or planks are usually set on edge along the borders of the roadway, as shown at e, e, in Figs. 5, 6, and 7; these stones are called **curbs,** or **curbing.**

FIG. 8

They are usually set vertically on edge, but are sometimes set somewhat sloping.

In some cases, earth or gravel roadways have gutters paved with cobblestone, as shown in Fig. 8, no curbs being set.

The top of the curbing is usually set to the grade line adopted for the street, or at the same elevation as the center or crown of the street.

MATERIALS AND CONSTRUCTION

16. Materials for Curbing.—The materials most commonly employed for curbstones are natural stones, such as granite, sandstones, etc., dressed to suitable form, and artificial stone, composed of hydraulic-cement concrete. Fireclay, cast iron, and wood are sometimes employed. Natural stone is the material generally used in localities where obtainable; in localities where natural stone is not obtainable, artificial stone is probably the best material, though slabs of burnt fireclay make excellent curbs and are

much used with brick pavements. Granite is generally considered the best material for curbs, though sandstone and limestone are both used. Cast iron and wood are not very suitable for the purpose, although wood is extensively employed in the residence streets of small cities.

17. Form and Dimensions of Curbstones.—The form and dimensions of curbstones vary considerably in different localities, and, being largely matters of appearance only, are not subject to rigid requirements of construction. Curbstones vary from 4 to 12 inches in width, from 8 to 24 inches in depth, and from 3 to 6 feet in length, according to the requirements of specifications, depth of gutter, etc. The depth of a curbstone should always be sufficient to prevent the stone from turning over or tipping toward the gutter; this condition will depend somewhat on the width of the stone; the length should not be less than 3 feet.

The front face of the curbstone should be hammer-dressed to a depth somewhat greater than that exposed above the gutter; where the sidewalk joins the curbing, the back of the curbstones should be dressed to a sufficient depth to allow the sidewalk pavement to fit closely against it. The ends of the curbstones should be dressed throughout their exposed depth, and the portion below the gutter surface should be so trimmed off as to permit them to be laid with close joints. The top surface of the curbstones should be dressed to a bevel corresponding to the slope of the adjoining sidewalk. The bed of the curb should generally be not less than 6 inches in width. Curbstones are sometimes made hollow, in order to provide conduits for electric wires, pipes, etc.

18. Setting Stone Curbing.—Great care should be exercised in setting the curbing; it should be set true to line and grade. The curb should always be bedded firmly on a solid foundation. The work should be thoroughly and substantially done, in order that the curbing will keep its proper position, and not sink nor tip toward the gutter.

Curbing is set in various ways: it is sometimes set directly on the earth foundation, sometimes on a gravel foundation,

and sometimes on a concrete foundation; the last-mentioned method is by far the best. The foundation of the curb

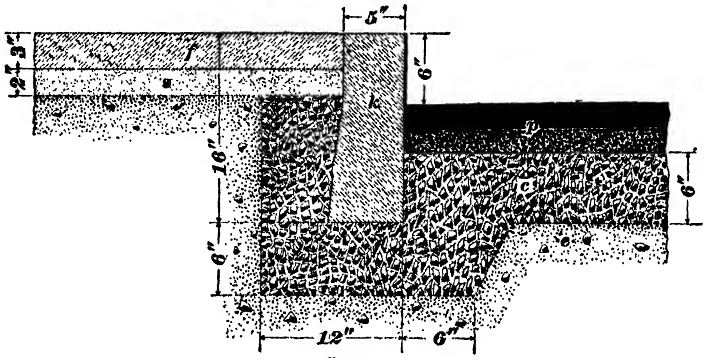


FIG. 9

should be made continuous with the foundation of the pavement. A curb set in concrete is shown in Fig. 9: *e* is the natural earth; *c*, the concrete foundation; *p*, the wearing sur-

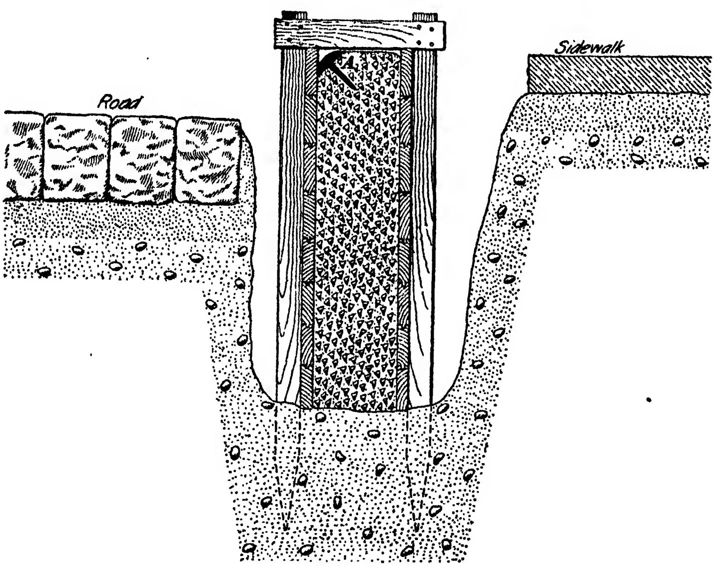


FIG. 10

face of the roadway pavement; *k*, the curbstone; and *f*, the sidewalk flagging. The common dimensions of the different

parts are marked on the figure. The wearing surfaces of roadway pavements are of different thicknesses, according to the material used.

19. Concrete Curbs.—A simple form of concrete curb is shown in Fig. 10. This curb is usually built in wooden molds, as shown, which are removed after the concrete has set. The concrete should not be poorer than 1 part Portland cement, 2 parts sand, and 5 parts broken stone. The stone should be hard and durable, and the concrete well spaded against the sides of the molds to insure a smooth surface. The top should be troweled smooth.

This form of curb is divided into certain definite lengths of from 6 to 10 feet, by breaking its continuity with sheets of tar paper or the like. These joints insure that all cracks due to shrinkage be vertical and at definite points. As shown at *A*, a steel guard is sometimes put on the curb to protect the concrete when wagons are backed up against it. This form of curb may be set on a wide concrete base, the same as a stone curb.

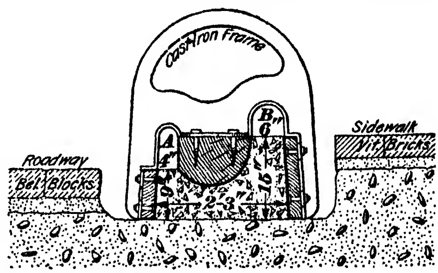


FIG. 11

20. Concrete Curb and Gutter.—Fig. 11 shows a method of laying a combined curb and gutter. The form consists of two 2-inch planks, each 10 feet long, with the edges and inside surfaces covered with sheet iron. One plank is 15 inches wide, and forms the side of the curb next to the sidewalk; the other is 9 inches wide, and forms the side next to the street. Both planks are held rigidly in place by three cast-iron frames. The frames also carry the form, the curved under surface of which produces the trough of the gutter, and the outside (or street side) of which forms the curb. The mold, which is shown in cross-section, is accurately secured in line at the proper grade by observation

along its top edges. It is then staked down by four long iron stakes or spikes that hook over the outside edges; this is to prevent any movement during the process of ramming in the concrete filling. The mixed concrete is shoveled into the openings *A* and *B*, and thoroughly rammed until the mold is full. The top surfaces at *A* and *B* are then troweled off flush with the top edges of the mold.

As soon as the concrete filling has become sufficiently set, the stakes are withdrawn, the mold is lifted off and moved along the line of the work, and placed in position to continue the process. When the mold is removed, the trough of this combined curb and gutter must be smoothed with a trowel in places where the concrete may not have been well rammed, in order to produce a more even surface. This may be done with neat cement mortar, or with mortar having one part of cement to two parts of sand. The smoothing requires no special skill, and may be rapidly done.

Several lengths of mold may be used at one time, so that when the last is full the first will be ready to move along the line without loss of time. As soon as the concrete becomes sufficiently hard, the street and sidewalk pavement may be laid to join it. This form of combined curb and gutter, being less deep, is liable to be heaved by frost, and, hence, is less stable than the simple curb described in Art. **19.**

FOOTWALKS AND STREET LAWNS

GENERAL DESCRIPTION

21. Sidewalks.—Footwalks for the accommodation of pedestrians are placed along both sides of streets, between the curbing and the property line; such foot-walks are commonly called **sidewalks**. They are constructed of different materials, such as gravel, wood, brick, stone, concrete, asphalt, etc., and are generally given such widths and placed at such heights as will best accommodate the conditions of each case.

22. Widths and Heights of Sidewalks.—On business thoroughfares, the entire space between the curbing and the building line is usually occupied by the sidewalk, which commonly consists of stone or other substantial material. The edge of the sidewalk adjacent to the curbing is always placed at the same elevation as the curbing, i. e., at grade; but the edge adjacent to the buildings is elevated somewhat above this, giving a slight inclination toward the gutter for drainage.

On residence streets, the construction of sidewalks does not follow any rigid rule; they are generally given widths of about one-fifth to one-sixth the width of the roadway, or from about 5 to 10 feet. The outer edges of the sidewalks on residence streets are commonly placed about 2 feet from the fence line.

The sidewalks of residence streets are generally placed at grade wherever the natural cross-section of the street is sufficiently level for this to be done without inconvenience or disadvantage to the adjoining property. It is decidedly the best practice to put all sidewalks either at a grade or at a certain small fixed distance (3 or 4 inches) above grade; this

is especially true of the sidewalks of paved streets. In many cities, however, the elevations of the sidewalks in residence districts are varied materially from the street grades, wherever such variation will better accommodate the adjoining property. This is illustrated in Fig. 12, in which, in order to accommodate the elevated position of the adjacent property, the sidewalk on one side of the street is elevated considerably above the surface of the roadway. Such practice should be avoided whenever possible, as the resulting appearance of the street is not nearly so good as when both sidewalks are placed at grade. This is a matter that is not usually left wholly to the discretion of the municipal engineer,

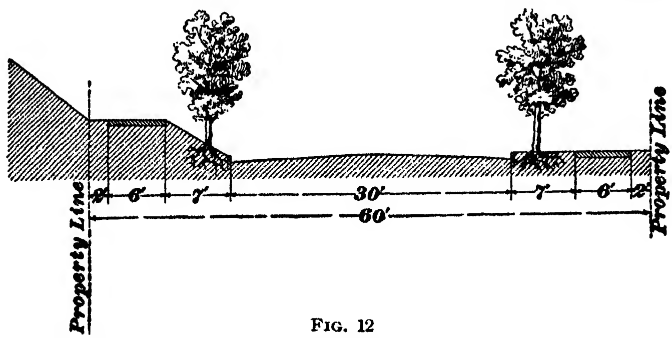


FIG. 12

however, but is often regulated by city ordinance, or, possibly, by some provision of the city charter.

23. Lateral Slopes of Sidewalks.—For the purpose of drainage, sidewalks should have a slight lateral slope toward the curb. On business streets that are closely built up, in which the entire width between the curb and the building line is occupied by the sidewalk, this lateral slope of the sidewalk will fix the elevations on the building line. The edge of the sidewalk adjacent to the curb will be placed at the elevation of the curb, that is, at the street grade, and the edge of the sidewalk adjacent to the building line will be higher or above grade an amount equal to the width of the sidewalk in feet multiplied by the lateral slope per foot. In some cities, a lateral slope of 2½ per cent., or 1 in 40, is given to the sidewalks; a slope of 2 per cent., or 1 in 50,

however, is generally very satisfactory for this purpose, and will here be adopted for all problems. All that portion of the street between the curb and the property line* should be given this uniform lateral slope, whether wholly occupied by the sidewalk or not.

24. Street Lawns.—Those portions of a residence street not occupied by the roadway and sidewalks should be laid out as lawns, with at least one row of trees on each side of the roadway. In Fig. 13 is shown the cross-section of a residence street 80 feet wide, having a roadway 40 feet in width and two sidewalks each 8 feet in width. A single row of trees is shown on each side of the roadway, between the

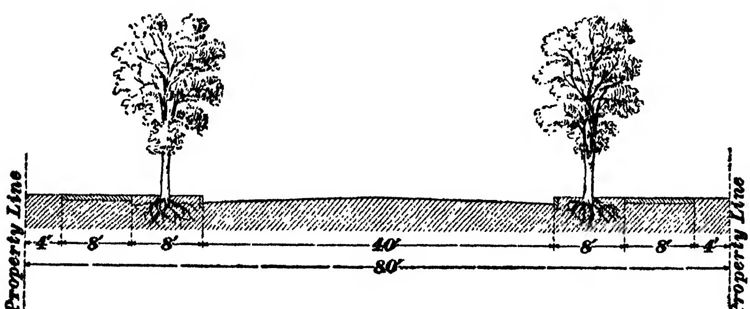


FIG. 13

sidewalk and the curbing. With these widths, however, if the residences are set well back from the property line, another row of trees could be advantageously introduced between the sidewalk and the property line.

In cases where the lawns are of liberal widths, two rows of trees are sometimes set along each side of the roadway between the sidewalk and the curbing, as shown in Fig. 14, which represents the cross-section of an avenue 120 feet wide, having a roadway 50 feet wide and two sidewalks 10 feet wide each. The arrangement there shown is generally well

* The boundary line of a street, or the dividing line between the street and the adjoining property, is known variously as the *property line*, *building line*, *block line*, *fence line*, and, sometimes, *street line*, though the latter term is more commonly applied to the center line of the street.

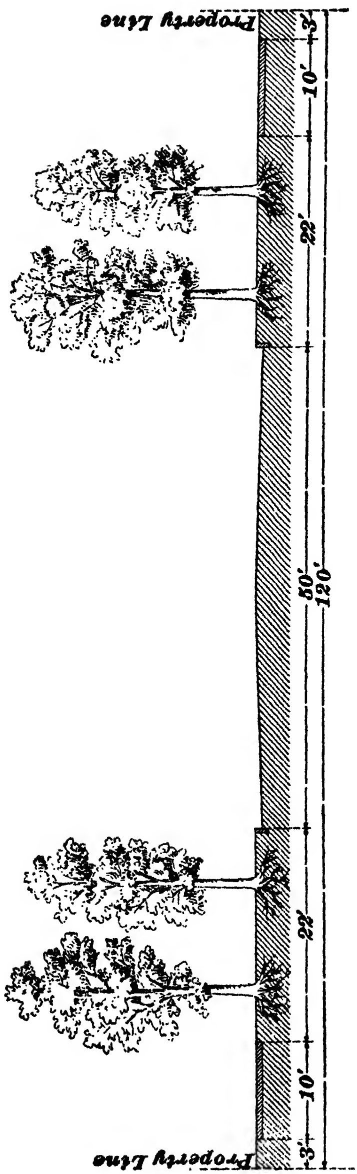

Property Line
3'
10'
22'
50'
120'
22'
10'
3'
Property Line

Fig. 14

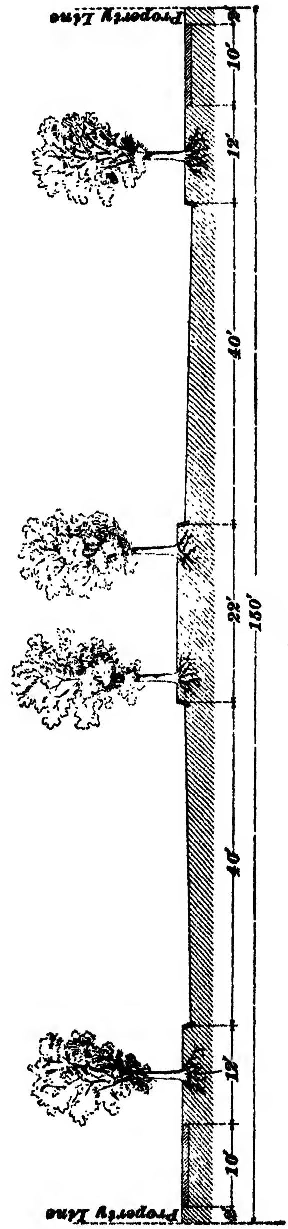

Property Line
10'
12'
40'
22'
150'
40'
12'
10'
Property Line

Fig. 15

adapted to avenues of this width. In some cases, the sidewalk is placed nearer the curbing, leaving most of the lawn space between the sidewalk and the property line. This is not so good an arrangement as that shown in Fig. 14, however, because the position of the sidewalk is neither as pleasant for pedestrians nor as conveniently accessible to the residences. Very broad avenues sometimes have two roadways, which are separated by a lawn extending along the center of the avenue and containing one or two rows of trees. Such avenues are commonly called **boulevards.** The cross-section shown in Fig. 15 is somewhat similar to that of the Western Boulevard in the City of New York.

The importance to a city of clean and well-kept lawns can scarcely be overestimated. They serve not only as a means of ornamentation, but also as a means of purifying the air, and thus have a beneficial effect on the health of the inhabitants. Pure air is none too plentiful in a crowded city, and one of the most effective purifying agents is healthy growing vegetation, such as trees and clean grass.

CONSTRUCTION OF FOOTWAYS

25. Materials for Footways.—The materials most commonly used for footways are natural and artificial stone, brick, asphalt, wood, tar, concrete, and gravel.

26. Natural-stone footways are generally durable and satisfactory; sandstone, limestone, slate, and granite are employed. Of these, a good quality of sandstone gives the most satisfactory results: when of compact texture, it absorbs comparatively little water, and soon dries after rain; it also wears well without becoming very slippery. Limestone does not usually wear so well. Granite, though it wears exceedingly well, becomes very slippery.

27. Artificial stone is extensively used for paving footways. When the materials are good and the work is properly done, this form of footway is one of the best. These footways are constructed in one of two ways; namely,

from slabs of the artificial stone manufactured at a factory and laid in the same manner as natural stone, or by forming the artificial stone in its proper position in the footway; the latter is the plan more commonly adopted.

28. Bricks of suitable quality, if carefully laid on a proper foundation, form an excellent footway pavement for the streets of residence and suburban districts, and also for the main streets of small towns.

29. Asphalt pavement forms an excellent footway; it is durable, agreeable to walk on, and does not wear slippery; it is used both in the form of sheet asphalt and in the form of compressed tiles.

30. Wood in the form of planks has been extensively used for footways. This material makes footways that are cheap in first cost, and when in good condition are pleasant to walk on. They soon get in bad condition, however, and not only require constant attention and repairs, but also become unpleasant and even dangerous for pedestrians.

31. Tar concrete has been extensively used for footways in several cities. It has not proved satisfactory. The footways soon become so worn and deteriorated as to be very disagreeable to walk on. They are greatly affected by changes of temperature, rapidly disintegrate, and are at best of but a temporary nature.

32. Gravel makes an excellent footway pavement for suburban districts, parks, and pleasure grounds. If properly constructed and well drained, such pavement forms, in the proper localities, a pleasant and durable footway.

33. Construction of Natural-Stone Footways.—The slabs or flagstones should be not less than 3 inches thick and of uniform thickness throughout; each stone should contain not less than 12 square feet of superficial area; the top should be cut evenly, and the edges should be dressed square throughout the full depth of the stone. The flagstones should be laid on a bed of sand or clean, gritty earth; they should be well bedded in the sand foundation and

settled to a solid, even bearing. The joints should be closed with hydraulic-cement mortar.

34. Construction of Artificial-Stone Footways.—Several varieties of artificial stone are used; the process of manufacture is practically the same for all kinds, however, the difference being due to variations in the materials employed and the proportions used. Portland cement, sand, gravel, and broken stone are the materials commonly employed. When the stones are manufactured in the form of slabs at a factory, they are laid in the same manner as natural stone.

When the artificial stone is manufactured in place in the footway, the process should be substantially as follows: The ground should be excavated to a depth of not less than 8 inches below the intended surface of the finished pavement, and to such greater depth as may be necessary to secure a solid foundation and remove all perishable material. Where the excavation is deeper than 8 inches, the deficiency should be filled with suitable material, as sand or cinders, and the entire surface well compacted by ramming. On this natural foundation should be spread a layer of gravel, cinders, clinker, broken stone, or similar material, which should be well consolidated so as to have a finished thickness of about 4 inches. On this should be spread a layer of hydraulic-cement concrete, the composition of which may be as follows:

Material	Parts by Measure
American hydraulic cement	1
Sand	2 to 3
Gravel and broken stone	5 to 7

This concrete should be spread in molds formed of strips of boards about ½ inch in thickness set on the gravel or cinder foundation and adjusted to the required grade and slope; these strips should also be placed along the outer edges of the walk. The layer of concrete should have a thickness of about 3½ inches when thoroughly consolidated by ramming. After the concrete has set, it should be covered

with a wearing coat composed of equal parts of Portland cement and clean, sharp sand; this should be from ½ to 1 inch in thickness, as may be required. The surface should be neatly troweled to the proper grade.

After the concrete is set and before the wearing coat is spread on it, the strips of wood used for molds should be removed; this will leave joints about ½ inch wide between the blocks of artificial stone, which in some processes are filled, and in other processes left open. Perhaps more commonly a sheet of tar paper separates the blocks of concrete, the lateral mold plank being removed after the concrete is placed on one side of it and before the concrete is placed on the other side.

The pavement should be kept damp by frequently sprinkling it with water for a period of at least a week, and should also be protected from the heat of the sun by a covering of damp sand. Travel should be kept off the pavement for about 10 days, or until the concrete has thoroughly set.

35. Construction of Brick Footways.—Selected paving bricks should be used for footways; the bricks should be of suitable quality and of uniform size and texture. While what are known as *vitrified paving bricks* used for roadway paving make the best sidewalk bricks, those commonly used are simply very hard-burned building bricks known as *paving bricks* or *sewer bricks*.

For the best construction, a foundation of hydraulic-cement concrete should be prepared, on which the bricks should be set on edge in hydraulic-cement mortar, their joints being filled flush with the mortar. The more common construction, however, is generally about as follows: The ground is excavated to a depth of 10 inches below the surface of the intended pavement, and as much farther as may be necessary to obtain a solid foundation and remove all objectionable material, the space being filled to the proper level with clean sand, gravel, or other suitable material. On this foundation is placed a layer of fine, clean, sandy gravel, containing no pebbles larger than 1½ inches in greatest dimension, the

gravel having a depth of not less than 4 inches when consolidated. After this layer has been thoroughly consolidated by rolling or ramming, a layer of fine, clean, sharp sand 4 inches in thickness is spread on it to serve as a bed for the bricks. The surface of this sand bed is made parallel to the intended surface of the finished pavement and brought to a depth below it equal to a little less than the thickness of a brick.

The bricks are laid flat on this bed of sand, either at right angles to the line of the footway, or diagonally in the manner known as the **herring-bone style**, the bricks being of uniform width and depth and so laid as to break joints longitudinally by a lap of not less than 2 inches. In laying the bricks, the pavers stand or kneel on the bricks already laid, so as not to disturb the bed of sand. When thus laid, the bricks are immediately covered with fine, clean, sharp sand, free from clay, loam, or earthy matter; they then are carefully rammed by striking with a heavy hammer on a plank placed over several courses. The ramming is continued until the bricks are settled to a solid, unyielding bed. When the ramming is completed, fine, dry sand is spread over the surface and swept into the joints.

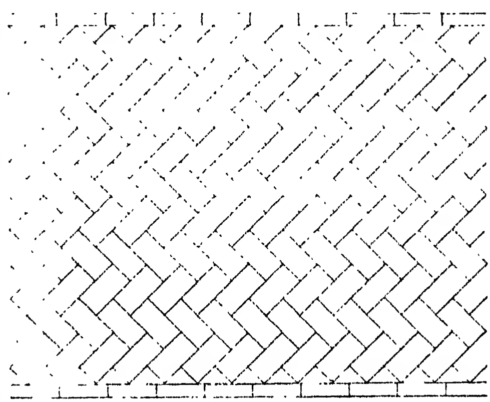


Fig. 16

The plan of a portion of a brick footway laid in this manner is shown in Fig. 16. It will be noticed that when the bricks are laid in this way, a special triangular form of bricks is required to fit against the curbing at the sides of the footway, which is formed by bricks set on edge. Usually these are cut from whole brick by the paver.

36. Construction of Sheet-Asphalt Footways.—Sheet-asphalt footways are constructed in about the same manner as the sheet-asphalt pavements for roadways, except that the construction is of a lighter character. The ground should be excavated to a depth of 3 inches below the intended surface of the pavement, and to a greater depth where necessary in order to remove unsuitable material and secure a firm foundation, the deficiency being filled with clean gravel or other proper material; this foundation should be thoroughly rolled or rammed. On the foundation thus formed should be spread a layer of clean broken stone, to such depth that, after compacting, it will have a thickness of 2 inches. When this has been compressed by rolling and tamping, a binding material consisting of coal-tar distillate or distillate paving cement should be poured over it at a temperature of about 250° F.; about ½ gallon of the binding material should be used to each square yard of pavement; it should be poured on the broken stone in such a manner as to thoroughly coat the stones and fill the interstices.

The wearing surface should consist of asphalt paving cement, with which should be mixed crushed stone or crushed stone and sand; with this mixture may be combined a large proportion of the old asphaltic paving material taken up in repairing the wearing surface of asphalt pavements. The proportions should be about as follows:

Material	Per Cent.
Old paving material	69 to 76
Crushed stone	26 to 15
Asphalt paving cement	5 to 9

The crushed stone should not exceed ¼ inch in greatest dimensions, and should consist largely of stone dust. This should be mixed with the old paving material, which should be broken into small pieces. The mixture should be heated to a temperature of about 300° F., the asphalt paving cement added, and the whole thoroughly mixed by stirring. The material should be delivered on the pavement at a temperature of from 250° to 275° F., and spread on the base by

means of hot iron rakes to such depths as will give a thickness of 1 inch after compression. It should then be thoroughly compressed by rolling and ramming, during which process a small amount of hydraulic cement should be swept lightly over the surface.

37. Construction of Compressed-Asphalt Tile Footways.—The compressed-asphalt tiles used for footways are formed in nearly the same manner as the asphalt paving blocks; the tiles, however, are usually 8 inches square and

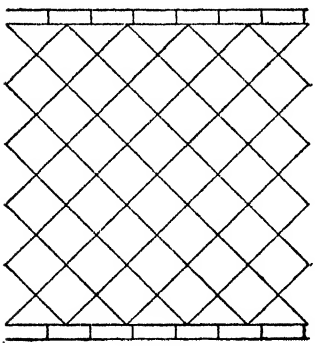


FIG. 17

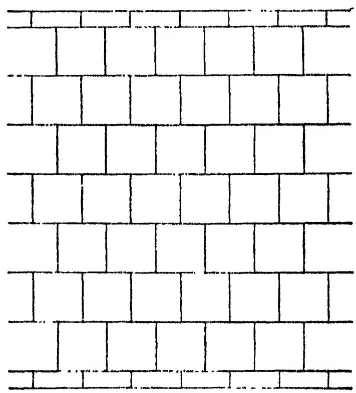


FIG. 18

$2\frac{1}{2}$ inches thick. The construction of these footways is almost identical with the construction of brick footways, as described in Art. **35**, and the description need not be repeated. Two methods of laying the tiles are shown in Figs. 17 and 18.

38. Construction of Wood Footways.—Wood footways are commonly constructed of pine plank 2 inches in thickness and surfaced on the upper side, laid crosswise of the walk on wooden stringers 4 in. $\times$ 4 in. in cross-section; the stringers are laid longitudinally and bedded in the earth. The construction is so familiar as to require no further description here.

39. Construction of Gravel Footways.—Gravel makes a very excellent footway pavement for suburban and

country roads, parks, pleasure grounds, etc. The same principles apply to the construction of gravel footways as to the construction of gravel roads, the chief requirements being that they must be thoroughly drained and well compacted by rolling. The use of gravel as a road material and the construction of gravel roads are treated at great length in *Highways*, and it will not be necessary to add anything to what is there given. The greatest agency of destruction affecting gravel footways is that of storm water flowing over the walks, washing out gulleys, and otherwise damaging them; hence, it is essential in their construction that water from adjoining slopes be, as much as possible, kept off them, and that adequate drainage be provided for such water as does come on them.

CROSSING STONES

40. Use of Crossing Stones.—At street intersections, or wherever the footway of one street crosses the roadway of another street, it is customary, in order to make the footway continuous, to lay two or more rows of stone slabs across the roadway. For the convenience of pedestrians, these are laid at as near the grade of the footway as circumstances will permit. Such stones are called **crossing stones** or **bridge stones.** They are generally laid at the street intersections in stone pavements, but are commonly omitted from the smoother pavements, such as asphalt and brick.

41. Size and Quality of Stones.—Crossing stones should be not less than 3 nor more than 8 feet long, and of uniform width and thickness; the width should not exceed 2 feet nor be less than 10 inches, and the thickness should be from 6 to 8 inches; the top surface should be hammer-dressed, and the ends should be dressed square the full depth of the stones, so as to form close joints. A suitable quality of sandstone is the best material for crossing stones; it is superior to granite for this purpose, because its surface does not wear smooth and become slippery, as does granite. The manner in which crossing stones are laid will be understood

from Fig. 19, which is a view of a portion of a street intersection, showing the crossing stones: *p* is the wearing surface of a granite-block pavement, *g* is the gutter, *k* is

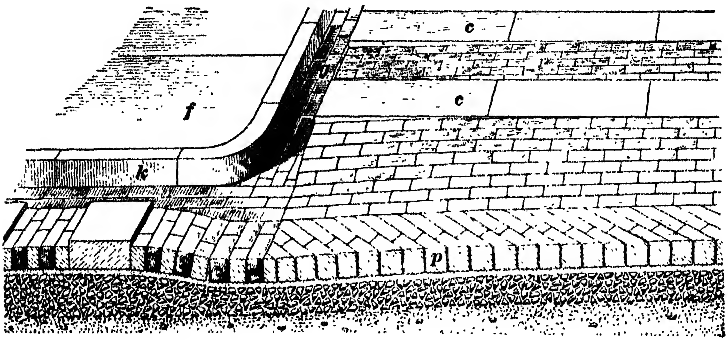


FIG. 19

the curbstone, and *f* is the flagstone of the sidewalk; *c*, *c* are the two rows of crossing stones.

STREET INTERSECTIONS

42. The proper arrangement of the grades at street intersections is often a troublesome matter. Where two streets intersect, it is desirable that the crown of each street shall be continuous to the center of intersection, and that the grade of each street shall continue uniform to the center of intersection. These two results cannot always be obtained. In Fig. 20, AB and CD are the center lines of two streets intersecting at right angles. The points *a*, *c*, *d*, and *b* are the corners of the curbing, and are called **curb angles,** or **curb corners.** Instead of being really angles, however, as shown in the figure, they are often the quadrants of small circles.

Let it be assumed that the total width of each street is 60 feet and that the widths ac and ad of the two roadways are each 40 feet; also, that the grades of the street descend at the rate of 2 per cent. for AB and 5 per cent. for CD, in the directions indicated by the arrows. The grade lines

of both streets must have the same elevation at *o*, the intersection of the center lines. As computed by the grade of *A B*, the elevation of the curbing would be, at the points *a* and *d*, the amount $.02 \times 20 = .4$ foot above the intersection *o*, and, at the points *c* and *b*, the same amount below it.

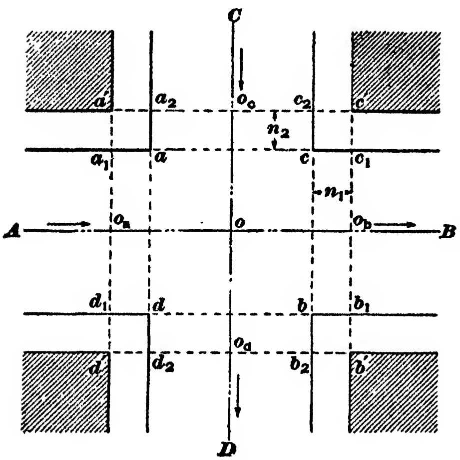


Fig. 20

As computed by the grade of *CD*, however, the elevation of the curbing at *a* and *c* would be $.05 \times 20 = 1$ foot above the intersection *o*, and at *d* and *b* it would be the same amount below it. Consequently, the following elevations, with reference to the intersection *o*, are obtained for the curbing at the points *a*, *c*, *d*, and *b*, elevations above being indicated by the + sign and elevations below by the − sign:

Curb Angle	On Grade of *A B*	On Grade of *CD*	Difference
a	+ .4	+ 1	.6
c	− .4	+ 1	1.4
d	+ .4	− 1	1.4
b	− .4	− 1	.6

In the last column is given the difference between the elevations of each curb angle, as determined from the two different grades. It is evident, however, that each angle of the curbing can have but one elevation. To harmonize as far as possible these conflicting conditions is a problem that is in some cases very difficult of solution, and one concerning which different views are held. Some of the methods employed will now be explained.

METHODS OF ADJUSTMENT

43. Method by Adjustment at Curb Angles.—When the grades of the intersecting streets are very light, so that the difference in the elevations of the curb angle, as determined from the two grade lines, is small, the curbing of each street may be carried at the street grade through the entire block to the property line of the intersecting street, and the adjustment of the elevations of the curbing may be made between the points where the curbings intersect the property lines. Thus, on the portion B of the street AB, Fig. 20, the curbs may be set to the regular street grade as far as the points c_1 and b_1 on the property line of the intersecting street CD; and on the portion C of the street CD the curbs may be placed at the regular street grade as far as the points a_2 and c_2 on the property line of the street AB. The elevations of the curbing at the points c_1 and c_2 being thus fixed at the grades of the respective streets, the elevation of the curb angle may be determined by giving the curb a uniform grade between the points c_1 and c_2. More satisfactory results will generally be obtained, however, by making the elevation of the curb angle *a mean between its different elevations as given by the grade lines of the two streets;* the elevation of the curb angle will here be determined in this manner for this method of adjustment. This method of adjustment, however, will not be satisfactory where the grade of either intersecting street is at all steep.

44. Method by Independent Curb Grades.—A better method of adjusting the elevations of the curbing, where the grade of each street continues uniform to the center of intersection, is to set the curbs at independent grades through the block from curb angle to curb angle. Having determined the elevations of the curb angles at the two adjacent corners of a block, by calculating for each its elevation according to the grade of each intersecting street, and taking the mean of the results, as in the preceding method, the grade of the curbing is made uniform through the block from curb angle

to curb angle, provided that there is no change in the rate of the street grade along the block between the curb angles. If the rate of the street grade changes at one or more points along the block between the curb angles at its adjacent corners, the grade of the curbing should be made uniform from the elevation fixed for each curb angle to the elevation of the street grade at the nearest change. In some cases, it may be found advisable to fix the elevations of the curb angles somewhat above or below the mean of the elevations calculated from the two street grades.

45. Method by Level Intersections.—Another method of adjusting the grades at street intersections is to make the grade of each street level across the intersecting street, either from property line to property line or from curb line to curb line. The total amount of rise or fall necessary to each street between any two successive intersecting streets will be effected wholly along the block between the property lines of the block, or between the curb lines of the two intersecting streets, as the case may be.

If the rise or fall is effected wholly between the property lines of the block, then, at the property line of each intersecting street, the grade changes to a level grade and continues level across the full width of the street. At the points o_a, o_c, o_d, and o_b, Fig. 20, where the center line of each street crosses the property lines of the intersecting street, the grade lines have the same elevation as at the center o of the intersection. The elevation of the curb will require no special adjustment; at every cross-section of the street it will be the same as that of the street grade directly opposite. At the points a, a_1, and a_2, c, c_1, and c_2, etc., the curbs will have the same elevation as the points o_a, o_c, etc., and as the center o of intersection.

The results will generally be more satisfactory if the changes of grade for each street are made at the curb lines of the intersecting street. This will give a slightly greater distance in which to attain the necessary rise and fall between two adjacent streets, and, consequently, a

slightly easier grade, and will allow the grade of the curb to continue uniform to the curb angle, giving a somewhat better appearance. Only that portion of the intersection included between the curb lines is made level. This level portion of the intersection will be the rectangle having its four angles at the curb corners, *a*, *c*, *d*, and *b*, Fig. 20; at these points, the tops of the curbs will have the same elevation as the center *o* of intersection.

By the method of level intersections, the problem of adjusting the system of grades is put in the simplest possible aspect. On this account, it is a very popular method and is much employed. On steep grades, however, it has the disadvantage of giving two abrupt changes in the grade line at every street intersection. Moreover, in ascending such a grade, the level intersections will have the appearance of *descending* in the opposite direction. This may be to some extent corrected by the following modification of the method.

46. Modification of the Method of Level Intersections (Laterally Sloping Roadway).—Where two streets intersect, it is not commonly the case that both streets have steep grades. If they intersect on a hillside, it will usually be the case that one street will have the same general direction as the slope and that its grade will be correspondingly steep, while the other street will have a direction across the slope or along the side hill, with a comparatively light grade. It will generally be advantageous to the residences and lawns along the side-hill street, as well as to the street intersections, to give the surface of this street a lateral slope in the direction of the general slope of the natural surface. With a sloping crown, this can be done by simply throwing the summit of the crown toward the upper side of the roadway. A somewhat similar effect can be accomplished in other ways, but this method will be the only one noticed here.

47. Eccentric Crowns.—The form of cross-section is shown in Fig. 21; it will here be called an **eccentric crown**. With the crown in this position, if the same uniform slopes are retained for the sides of the roadway, the top of the

curbing a', on the side nearer the summit of the crown, will be higher than that of the curbing b' on the opposite side, by the amount d, as shown in the figure.

If the street AB, Fig. 20, is given a cross-section of the form shown in Fig. 21, the curb angles a and d and the curb angles c and b of the former figure will correspond, respectively, to the curbs a' and b' of the latter figure, and the street CD, Fig. 20, may have the rate of grade $\frac{d}{w}$, Fig. 21, across the street AB, while in all other respects the intersection may be treated as a level intersection. The changes of grade should preferably be made at the curb lines.

The expedient of modifying the level intersection by giving a lateral slope to the roadway of the street extending along

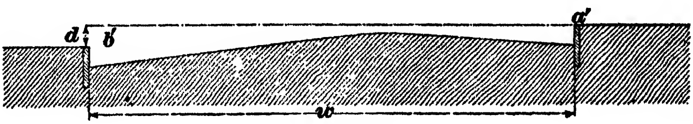


FIG. 21

the side hill can often be employed to good advantage. No adjustment of the grades of the curbs will be required, except, merely, such adjustment of the elevations of the curbing on the side-hill street as may be necessary to give the proper lateral slope to the street. The grade of this side-hill street, to which the lateral slope is given, should be level across the intersection. On the intersecting street, that is, on the street extending up and down the hill, the elevation of the curbing will then be the same as that of the street grade in the same cross-section. In the next article will be given formulas relating to the cross-sections of streets having eccentric crowns.

48. Formulas for Eccentric Crowns.—The cross-section of the roadway shown by a somewhat exaggerated outline in Fig. 22 is the regular form of cross-section with sloping crown, except that the summit o of the crown, instead of being at the center m of the roadway, is at a distance e from the center, and nearer the higher curb a'. This

distance e will here be called the **eccentricity of the crown.** For a cross-section having an eccentric crown, the length of the central curve joining the uniformly sloping portions of the surface line, and the rate of slope on the latter, should remain the same as though the crown were symmetrical; the rate of slope should be as given by formula **1** of Art. **11.** This being the case, the amount of eccentricity of the crown necessary to give the desired difference between the elevations of the curbs will be given by the formula

$$e = \frac{d}{2s} \qquad (1)$$

in which e = eccentricity of the crown, in feet;
d = difference in elevations of the curbs, in feet;
s = rate of slope as obtained by formula **1** of Art. **11.**

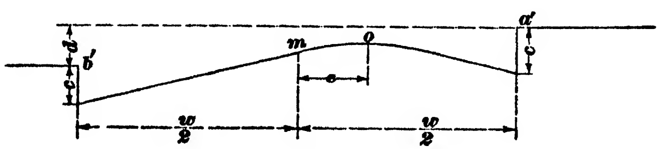


FIG. 22

The height of both curbs above the gutters or adjacent surface of the roadway should generally be made equal to the height of crown as given by the formula of Art. **7,** and as substituted in formula **1** of Art. **11,** to obtain the value of s. If both curbs have this height above the gutter, and the eccentricity of the crown is as given by formula **1** of this article, the elevation of the summit of the crown will be a mean between the elevations of the two curbs. In other words, the top of the higher curb a' will be at the distance $\frac{d}{2}$ above the summit of the crown, and that of the lower curb b' will be at the same distance below it. Although the rate of slope will remain unchanged, the height of crown will really be somewhat less in an eccentric than in a symmetrical crown.

Formula **1** of this article, for the eccentricity of the crown, does not apply correctly when d, the difference between the

elevations of the curbs, is greater than the value d_m given by the formula

$$d_m = s(w - b) \qquad (2)$$

in which s = rate of slope, as obtained by formula 1 of Art. 11;

w = width of roadway, as in formula 1 of Art. 11;

b = width of curved part of crown, as in formula 1 of Art. 11;

d_m = maximum difference between elevation of curbs to which formula 1 of this article will correctly apply.

49. Roadway With Uniform Lateral Slope.—When d has a value greater than that of d_m, as determined by applying formula 2 of Art. 48, the crown should be omitted, and the roadway surface should be given a uniform slope from curb to curb, as shown in Fig. 23. For a

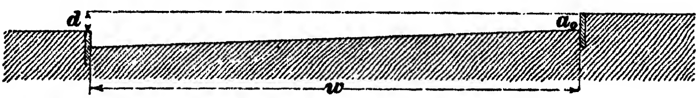


FIG. 23

cross-section of this form, the elevation of the highest point in the surface line of the roadway, or the point a_o, Fig. 23, should generally correspond to the elevation of grade. The rate per foot s_1 of uniform slope across the roadway, or the amount of vertical fall in each horizontal foot, will be given by the formula

$$s_1 = \frac{d}{w}$$

in which d = difference in elevations of curbs (Fig. 23);

w = width of roadway (Fig. 23).

The rate of slope s_1, as given by this formula, will generally be somewhat less than the rate of slope s, as given by formula 1 of Art. 11 and used in formula 2 of Art. 48. The height of each curb above the adjacent surface of the roadway may be made equal to the amount of theoretical crown c substituted in formula 1 of Art. 11 to obtain the value of s. The curbs, however, may have any desired

height above the surface of the roadway, so long as both curbs have the same height.

EXAMPLE.—For the roadway of example 2 of Art. **11**: (*a*) how much eccentricity must be given to the crown in order to elevate the top of one curb .48 foot above the top of the lower curb? (*b*) if the difference in the elevations of the curbs is .72 foot, will the formula for eccentricity apply correctly? (*c*) with this difference between the elevations of the curbs, if the surface of the roadway is given a uniform slope from curb to curb, what will be the rate of slope s_1?

SOLUTION.—(*a*) In the solution of the example referred to, the rate of slope s in the uniformly sloping portion of the cross-section was found to be .016; the difference d in the elevations of the curbs, as stated above, is .48 ft. By substituting these values in formula **1** of Art. **48**, the necessary amount of eccentricity for the crown is found to be equal to

$$\frac{.48}{2 \times .016} = 15 \text{ ft.} \quad \text{Ans.}$$

(*b*) The width of the roadway is 48 ft., and the width of the central curved portion is 5 ft. (Art. **11**). By substituting in formula **2** of Art. **48**, we have $d_m = .016(48 - 5) = .688$ ft. The difference of .72 ft. between the elevations of the curbs is greater than this value of d_m; hence, for this difference, the formula for eccentricity will not apply correctly. Ans.

(*c*) By applying the formula of this article, the rate of uniform slope across the roadway is found to be $\frac{.72}{48} = .015$. Ans.

EXAMPLES FOR PRACTICE

NOTE.—The following examples relate to the Examples for Practice given at the end of Art. **11**, in which sloping crowns were assumed. To the roadways of those examples, which are now, for convenience, assumed to have level grades, the formulas for laterally sloping roadways will be applied.

1. For example 2, the width of roadway is 20 feet and the height of crown is .44 foot. (*a*) What will be the value of d_m for this roadway? (*b*) If one curb is elevated .55 foot above the other, will the formula for eccentricity of crown apply correctly? (*c*) How much eccentricity of crown will be necessary to give this difference in the heights of the curbs?

Ans. $\begin{cases} (a) & .66 \text{ ft.} \\ (c) & 5 \text{ ft.} \end{cases}$

2. The width of roadway and height of crown for example 3 are 60 feet and .555 foot, respectively. (*a*) What will be the value of d_m for this roadway? (*b*) With a difference of 1 foot between the heights of the curbs, will the formula for eccentricity of crown apply correctly?

(c) How much eccentricity of crown will be necessary to give this difference in the heights of the curbs?

Ans. $\begin{cases} (a) & 1.02 \text{ ft.} \\ (c) & 25 \text{ ft.} \end{cases}$

3. A broken-stone roadway on a 3% grade is 24 feet wide and the height of the crown is .415 foot. (a) What will be the value of d_m for this roadway? (b) If the top of one curb is placed .75 foot above the top of the other curb, will the formula for eccentricity of crown apply correctly? (c) If the roadway surface is given a uniform slope from curb to curb, what will be the rate of slope?

Ans. $\begin{cases} (a) & .664 \text{ ft.} \\ (c) & .03125 \text{ ft.} \end{cases}$

---

50. Elevations of Block Corners.—The angles of the property line, a', c', d', and b', Fig. 20, are commonly called **block corners.** With reference to the street AB, the block corner c' is opposite the point c_1 of the curbing where it crosses the property line of the street CD; but, with reference to the street CD, the same block corner c' is opposite the point c_2 where the curbing crosses the property line of the street AB. In the case of an intersection level between property lines, the curbs will have the same elevation at the points c_1 and c_2, in which case the elevation of the block corner c' will be the same as computed by the lateral slope of each sidewalk, in the manner noticed in Art. **23.** If the intersection is not level, however, the curbs will not have the same elevation at the points c_1 and c_2. In any case, the elevation of the block corner will be given by the formula

$$c' = \frac{c_1 + c_2 + s_o(w_1 + w_2)}{2}$$

in which c' = elevation of the block corner;

c_1, c_2 = elevations, respectively, of the two curbs at points opposite the block corner (Fig. 20);

w_1, w_2 = widths, in feet, between the block corner and the respective curbs (the widths $c'c_1$ and $c'c_2$, Fig. 20);

s_o = lateral slope per foot between curb and building line, which is here taken as .02 (Art. **23**).

EXAMPLE.—The curb cc_1, Fig. 20, is at a distance of 12 feet from the block line $a'c'$, and has a grade of 2 per cent., descending from c; the curb cc_2 is at a distance of 10 feet from the block line $b'c'$, and

has a grade of 5 per cent., ascending from c. If the curb angle c has an elevation of 102.48, what should be the elevation of the block corner c'?

SOLUTION.—The elevation of the curb at c_1 will be $102.48 - .02 \times 10 = 102.28$, and the elevation of the curb at c_2 will be $102.48 + .05 \times 12 = 103.08$. By applying the formula just given, the elevation of the block corner c' is found to be

$$\frac{102.28 + 103.08 + .02 \times (12 + 10)}{2} = 102.90. \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE

NOTE.—The following examples refer to Fig. 20.

1. The curb $a\,a_1$ has a grade of 2 per cent. ascending from a, and the distance $a\,a_1$ is 10 feet; the curb $a\,a_2$ has a grade of 5 per cent. ascending from a, and the distance $a\,a_2$ is 12 feet. If the elevation of the curb angle a is 102.48, what should be the elevation of the block corner a'? Ans. 103.10

2. The curb $d\,d_1$ has a grade of 2.10 per cent. ascending from d, and the distance $d\,d_1$ is 8 feet; the curb $d\,d_2$ has a grade of 4.85 per cent. descending from d, and the distance $d\,d_2$ is 12 feet. If the elevation of the curb angle d is 102.48, what should be the elevation of the block corner d'? Ans. 102.473

3. The curb angle b, which has an elevation of 102.48, is at a distance of 11 feet from the property line $b'\,c'$ and at a distance of 15 feet from the property line $b'\,d'$. The curbs $b\,b_1$ and $b\,b_2$ have grades of 2.20 and 5.24 per cent., respectively, both descending from b. What should be the elevation of the block corner b'? Ans. 102.226

---

51. Drainage at Intersections: Location of Catch Basins.—In order that vehicles may pass smoothly over street intersections, the crown of each roadway should be continuous across the intersection; the crown of either roadway should not be broken by the gutters of the intersecting street. It is evident, however, that some provision must be made for the storm water from the gutters on the upper side of each crown.

Each of the intersecting streets shown in Fig. 24 is assumed to have a descending grade in the direction indicated by the arrows marked along its center line, and the crown of each

street is assumed to be continuous. With such grades, the storm water from the gutter c_1 can flow around the curb angle c into the gutter c_2, as indicated by the curved arrow, and, likewise, the storm water from the gutter d_1 can flow around the curb angle d and find an outlet in the gutter d_2. The storm water from the vicinity of the curb angle b can flow away in either gutter b_1 or gutter b_2. In both of the gutters a_1 and a_2, however, the storm water flows toward the curb angle a, and, as there is no gutter leading away from this curb angle across the crown of either roadway, some provision must be made for the storm water from these gutters.

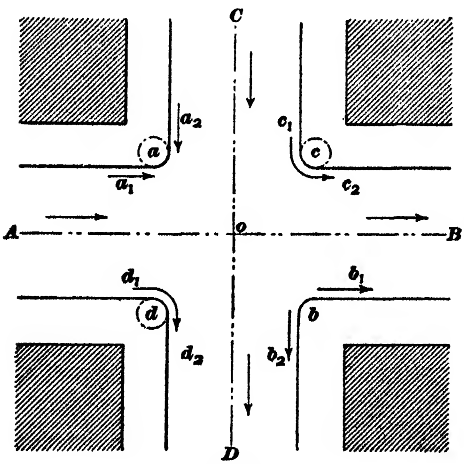


FIG. 24

If a storm-water sewer extends along either of the intersecting streets, the problem of providing for the storm water at the curb angle a may be easily solved by putting a catch basin at the curb angle, as indicated by the dotted circle. The storm water from the gutters a_1 and a_2 would be received directly by the catch basin, from which it would be conveyed to the sewer. Catch basins would also generally be placed at the curb angles c and d to receive the storm water from the gutters c_1 and d_1, so that the gutters c_2 and d_2 would not be overcrowded. It is evident that a catch basin would not be required at the curb angle b.

If there is no storm-water sewer along either of the intersecting streets, so that the storm water must be conveyed wholly by the surface gutters, it will be necessary to provide a conduit leading from the gutter at the curb corner toward which the water from both streets flows, corresponding to

the curb angle *a*, Fig. 24, across and beneath the roadway, discharging into the descending gutter, as the gutter c_2 or d_2, at some point far enough down to give the required depth below the roadway surface. In some cases, it may be advisable to provide such a conduit under each roadway.

GRADES

52. Objects to be Attained.—It is usually difficult to properly decide all the various matters that must be considered in fixing the grades for a system of streets and adjusting them so as to harmonize at intersections. The three main objects to be attained are: first, the prompt removal of the surface water; second, the easiest gradients; and third, the good appearance of the street.

53. Removal of Surface Water.—In order that the surface water may be promptly and effectually removed from a roadway, the rate of grade for the street should never be less than one-fourth of 1 per cent., that is, .25 foot per 100 feet; the grade should not be as flat as this except in extreme cases and with first-class pavements, such as brick or asphalt. A minimum grade of one-half of 1 per cent. is as flat as should generally be used, and a grade as steep as 1 per cent. is very desirable. Where the grade line has the same elevation at the intersecting streets at both ends of a block, instead of making the grade level between those streets, it should be elevated in the center of the block sufficiently to cause the water to flow in each direction toward the intersecting streets. If the street is sewered, the grade may be depressed at the center of the block by locating catch basins there; generally, however, it is better to elevate the grade at the center of the block.

54. Easiest Obtainable Gradients.—The matter of gradients will be governed largely by the character and slope of the natural surface and by the nature and extent of the improvements that have been made along the street. Where no improvements have been made, deep cuts and fills are

permissible in order to obtain favorable grades. But where buildings have been erected and improvements of a permanent nature have been made along a street before the grade is established, as is frequently the case, due regard must be given to such improvements in fixing the grade. The engineer must study the actual conditions as he finds them, and work out the most favorable grade possible under those conditions. This will seldom be as satisfactory a grade as could have been established before the improvements had been made, but it should be as free from abrupt changes and approach as near to a uniform grade between street intersections as possible, thus giving the easiest obtainable gradients. *It is very important that the grade of a street be established as soon as possible after the street is laid out and before improvements are made; the improvements should then conform to the established grade.*

55. Good Appearance of Street.—Although the matter of appearance has been placed last, it is by no means the least in importance. The general appearance of a street greatly affects the value of the adjacent property; it is, consequently, of great importance that the grade of a street be such as to give it a good appearance. Where possible, the grade of the street and the curb line should extend unbroken through each block from curb angle to curb angle. When it is necessary to change the grade at some point along the block, the change should be made at a property line and should be as small in amount as possible. Where the necessary change in the grade is considerable, the total change should be accomplished by means of several small, uniform changes, approximating a vertical curve, rather than by one abrupt change.

If residences have been built along the street before the grade is established, as is not infrequently the case, some attention should be given to the appearance of the lawns in fixing the grade; the appearance of all the lawns should be considered in the aggregate, however, rather than the appearance of any particular lawn. The appearance of the street

intersections must also be considered. In short, the appearance of the entire system of grades, as a whole, must be carefully considered, for it is their effect as a whole, and not the effect of any particular detail, that will be noticed.

56. General Methods of Procedure.—There is no established custom among municipal engineers in regard to the amount of grade, and practice varies materially. Indeed, some engineers prefer not to follow the same rule in regard to any two streets, but in each case to establish a grade and harmonize it with that of each intersecting street in such a manner as the conditions of that particular case may seem to demand. This is probably a better practice than to attempt to follow any rigid rule, for a method that would be satisfactory in one case would be likely to prove unsatisfactory in another.

In general, it is a good plan to fix first the grades of the streets extending in one direction, choosing the direction of the more important streets and taking them in the order of their importance; then fit in the grades of the cross-streets, taking them also in the order of their importance. In fitting in the grades of the latter streets, it will often be found advisable to modify more or less the grades of the former. If the system of streets is extensive, a contour map will often be of value as an aid in fixing the grades. When the street grades have been finally fixed, the grades of the curbs should be adjusted at the intersections in such a manner as may be best suited to each case.

57. Records of Grades.—A complete and systematic record of all grades should be preserved in a book kept for that purpose. Such a record is generally known as a **grade record.** For each street on which a grade is established, the grade record should give the rates of grade along the different portions of the street, with the elevation of each station, or, at least, of each street intersection and point where the grade changes. The information given should describe fully the grade of the roadway and that of each curb. This record should be supplemented by a complete and

GRADE RECORD

GRADE OF *MAIN STREET* FROM *FIRST STREET* TO *SECOND STREET*

Station	Left Curb			Roadway			Right Curb			Remarks
	Elevations		Rate of Grade	Elevations		Rate of Grade	Elevations		Rate of Grade	
	Surface	Grade		Surface	Grade		Surface	Grade		
12		108.36	×	108.4	108.36	×		108.36	×	Block line—First Street
13		110.36		110.6	110.36			110.36		
14		112.36	+2.00	112.9	112.36	+2.00		112.36	+2.00	
15		114.36		114.5	114.36			114.36		
+ 20		114.76		115.0	114.76			114.76		Block line—Second Street
+ 32		115.00	×	115.0	115.00	×		115.00	×	Curb line—Second Street
+ 50			0.0	115.1	115.00	0.0			0.0	Center line—Second Street
+ 68		115.00	×	115.0	115.00	×		115.00	×	Curb line—Second Street
+ 80		114.70		115.0	114.70			114.70		Block line—Second Street
16		114.20	−2.50	114.6	114.20	−2.50		114.20	−2.50	

accurate profile of the street. All information should be so well indexed as to be easily and quickly accessible.

The book in which the grade records are kept should be made especially for that purpose, with the pages so ruled as to be convenient for recording the grades. The best form for this record book depends somewhat on the engineer's ideas and methods in recording the grades. For most cases, the form given in the Grade Record on page 44 will be found satisfactory. The notes given are merely for the purpose of illustrating the method of recording the grade. It will be noticed that, in recording the rate of grade, a rising grade is indicated by a + sign, and a falling grade by a − sign; a rate of 0.0 is given for a level grade. In order that each station or plus where the grade changes may be easily distinguished, it is designated by an inclined cross (×) marked in the column for rate of grade.

CONSTRUCTION DRAWING

INTRODUCTION

1. General Remarks.—The general principles and rules governing the making of drawings are given in detail and thoroughly explained and illustrated in *Introduction to Construction Drawing*. The present Section contains directions for the drawing of three plates, each of which represents standard practice along special lines. The general method of procedure will be the same as in the Section referred to above; that is, the pencil drawings will not be inked in, nor will they be sent to the Schools; the tracings only, fully completed and lettered, are to be sent, one at a time, for correction.

Since the student has already had a great deal of practice in making drawings and tracings, it is deemed unnecessary to repeat here any of the directions given in preceding Sections, to which he should refer for particulars regarding general methods. He is also advised to consult the tracings that have been returned to him, and to read the corrections over very carefully. This will call to his mind his shortcomings on the earlier tracings, and enable him to do better work on succeeding plates. He will find that, as he gains in experience, he will have less and less difficulty in making good drawings and good tracings.

2. Drawing Plates.—The first of the three plates here described relates to railroad construction, and shows the standard methods of representing timber trestles, cross-sections of rails, and cross-sections of different kinds of

railroad roadbeds. The second plate treats of streets and pavements, and shows the methods used in practice to represent the cross-sections of roadways having granite-block, asphalt, and macadam wearing surfaces. In addition, there is given a plan of a part of a street intersection paved with granite blocks and having flagstone cross-walks. The third plate treats of details in connection with hydraulic work and shows the methods used to represent the cross-sections of earth dams with masonry center core walls, timber-crib rock-fill dams, and cast-iron water pipes with bell and spigot joints.

The plates will now be described in detail, and the methods of drawing them will be explained. The same types of letters will be used on the following plates as on preceding plates. These letters are made according to the directions given in *Introduction to Construction Drawing.*

DIRECTIONS FOR DRAWING THE PLATES

PLATE 104, TITLE: RAILROAD CONSTRUCTION

STANDARD RAIL SECTIONS

NOTE.—As in previous Sections, the notation Fig.* is used to indicate a figure on a plate, while the common form Fig. refers to a figure in the text. Thus, Fig.* 3 denotes figure 3 on the plate under consideration, while Fig. 3 denotes figure 3 in the text.

3. Figs.* 1, 2, and 3 are cross-sections of standard **T** rails used by the best railroads at the present time. **T** rails are usually of rolled steel, and are commonly finished to lengths of 30 feet, although other lengths are standard on some roads. Fig. 1 is a perspective view of a **T** rail 30 feet in length. Railroad **T** rails are specified by the weight in pounds per yard of length; for example, an 80-pound rail weighs 80 pounds per yard, a 100-pound rail weighs 100 pounds per yard. There is a great variety of weights, some roads using rails weighing as much as 110 pounds per yard. The weights shown in Figs.* 1, 2, and 3 are, however,

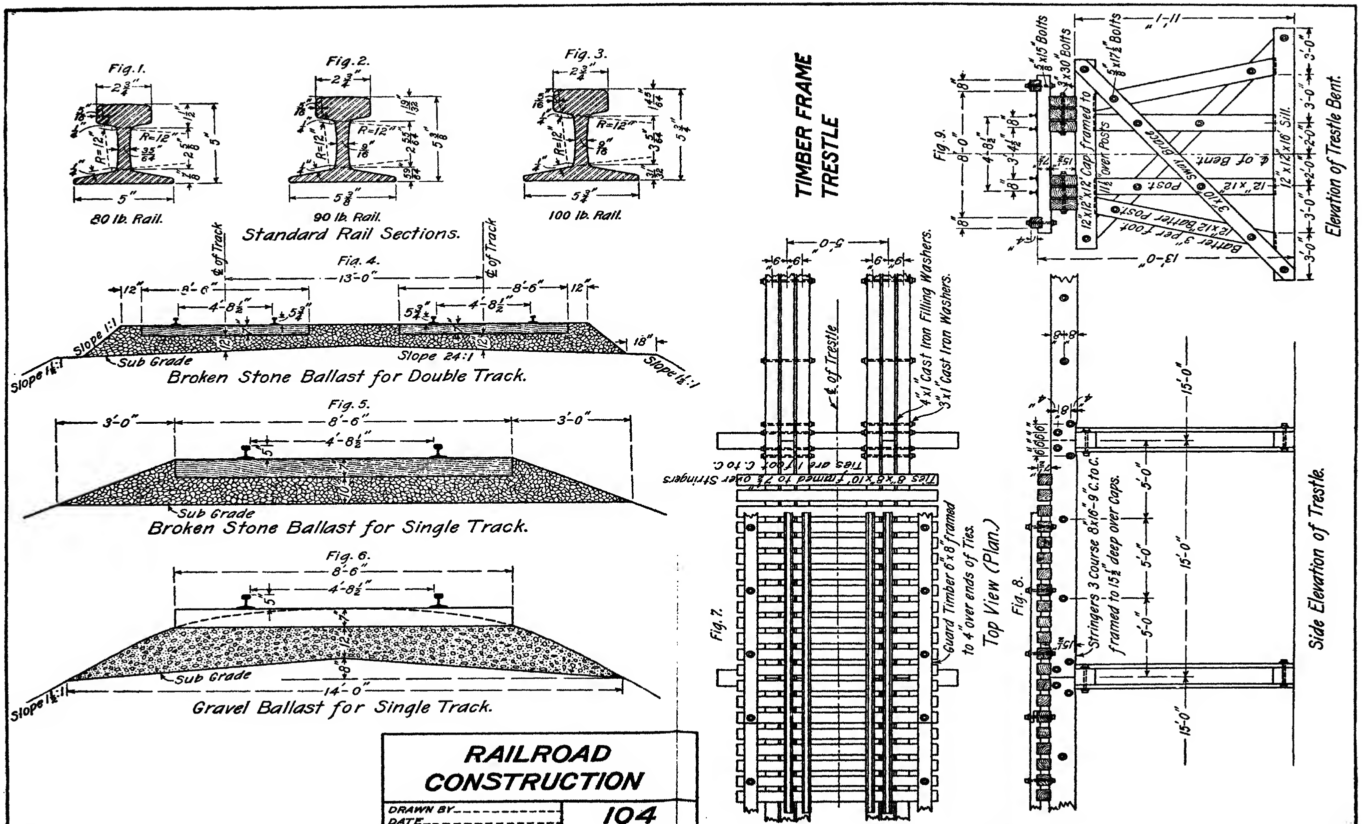


Fig. 1.
80 lb. Rail.
Fig. 2.
90 lb. Rail.
Fig. 3.
100 lb. Rail.
Standard Rail Sections.
Fig. 4.
Broken Stone Ballast for Double Track.
Sub Grade
Slope 24:1
Fig. 5.
Broken Stone Ballast for Single Track.
Fig. 6.
Gravel Ballast for Single Track.
TIMBER FRAME TRESTLE
Fig. 7.
Top View (Plan.)
Ties 8"x8"x10' framed to 7½" over Stringers
Ties are 1 foot C. to C.
Guard Timber 6"x8" framed to 4" over ends of Ties.
4"x1" Cast Iron Filling Washers.
3"x1" Cast Iron Washers.
Fig. 8.
Stringers 3 course 8"x16"-9" C. to C. framed to 15½" deep over Caps.
Side Elevation of Trestle.
Fig. 9.
12"x12"x12' Cap framed to 11½" over Posts
12"x12"x16' Sill.
12"x12" Post.
12"x12" Batter Post.
3"x10" Sway Brace
Batter 3" per foot
Elevation of Trestle Bent.
RAILROAD CONSTRUCTION
DRAWN BY
DATE
104

those most commonly used. Fig.* 1 represents an 80-pound rail; Fig.* 2, a 90-pound rail; and Fig.* 3, a 100-pound rail. The 80-pound rail shown in Fig.* 1 is sufficiently heavy for ordinary traffic on a first-class road; that shown in Fig.* 3 is sufficiently heavy for any road doing a very large business in heavy freight; that shown in Fig.* 2 is adapted to intermediate conditions.

The sections given on the plates are drawn to a scale of 3 inches to the foot. The lower line of each of these sections is $2\frac{3}{4}$ inches from the top border line. The center line of the section shown in Fig.* 1 is $1\frac{1}{2}$ inches, the center line

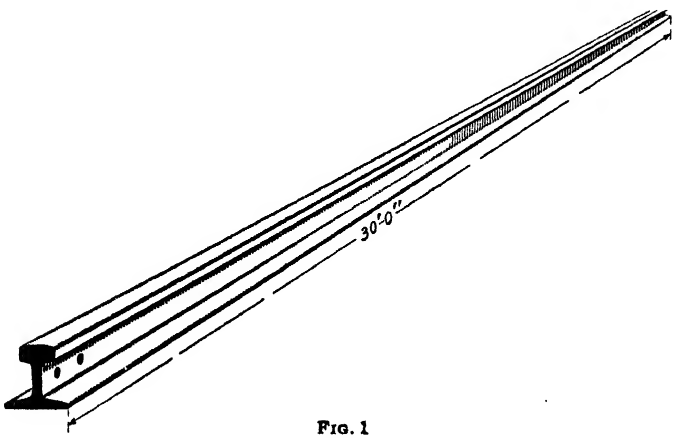


FIG. 1

of that shown in Fig.* 2 is $4\frac{1}{4}$ inches, and the center line of that shown in Fig.* 3 is $7\frac{1}{4}$ inches from the left border line.

4. The method of laying out the various dimensions is shown in Fig. 2. First, the bottom line *a a*, Fig. 2 (*a*), is drawn horizontal, and then the center line *b b* is drawn at right angles to it. Next, the points *c*, *d*, and *e* are marked on the center line at the proper distances from the base line; that is, the distances between these points, as shown on the right of the sections on the plate, are laid off to the scale of 3 inches to the foot. Next, the sloping lines for the bottom of the rail head and for the top of the base are drawn. These four lines make angles of 13° with the horizontal. The

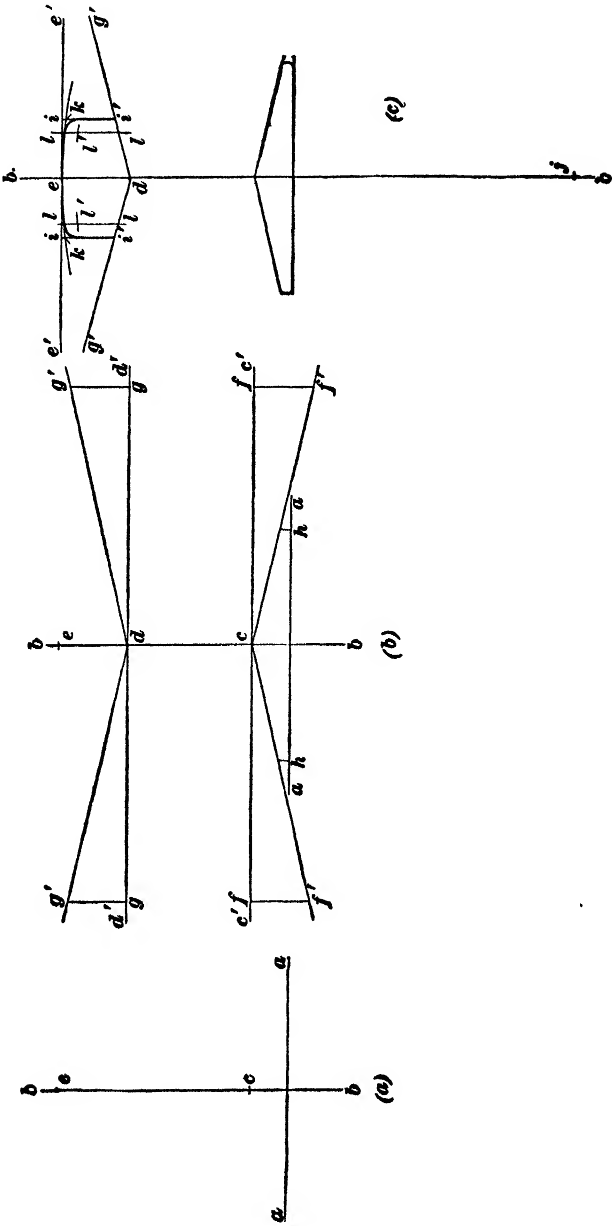


FIG. 2

angles can be laid out with a protractor, or by means of their tangents. The tangent of 13° is .231. To lay off this tangent, draw horizontal construction lines $c'c'$ and $d'd'$, Fig. 2 (*b*), through the points *c* and *d*, respectively, and mark points *f* and *g* on them at distances of 1 foot (to a scale of 3 inches to the foot) on each side of *b b*. Then lay off vertically below *f f* and above *g g* the distances ff' and gg' equal to .231 foot, or $2\frac{3}{4}$ inches, to a scale of 3 inches to the foot. Draw the lines dg' and cf'; these lines give the location of the sloping lines for the bottom of the head and top of the base. Next, lay off on *a a*, to a scale of 3 inches to the foot, the width of base given on the plate, laying off one-half on each side of *b b*; this gives the points *h*, *h*, Fig. 2 (*b*), through which verticals are drawn to their intersections with cf'. The top and bottom corners at *h*, *h*, the edges of the base, are not sharp, as shown in Fig. 2 (*b*), but are rounded to curves of $\frac{1}{16}$ inch radius. This is too small a radius to allow the curves to be drawn with the instruments, so these corners are usually slightly rounded freehand.

5. Next, draw the horizontal construction line $e'e'$, Fig. 2 (*c*), through *e*, and lay off on it, to a scale of 3 inches to the foot, the width *i i* of the head, as given in the plate, laying off one-half on each side of *b b*. Through the points *i* thus found, draw the verticals ii' to their intersections with the sloping lines dg'. The intersections at i' are rounded off freehand, the actual radius of the curves being $\frac{1}{16}$ inch. Lay off on *b b* the distance *e j* equal, by scale, to 12 inches; with *j* as a center and *e j* as a radius, describe an arc intersecting the lines ii' at *k*, *k*. The corners at *k*, *k* are rounded to curves of $\frac{5}{16}$ inch radius. To find the centers of these curves, draw lines *l l* parallel to ii', and $\frac{5}{16}$ inch from ii', by scale; with *j* as a center, and a radius equal to $12 - \frac{5}{16} = 11\frac{11}{16}$ inches, intersect the lines *l l* at the points $l'\,l'$; these are the centers of the curves. With the points l' as centers, and a radius equal to $\frac{5}{16}$ inch, draw in the curves. This completes the drawing of the base and of the head. The web is to be drawn next.

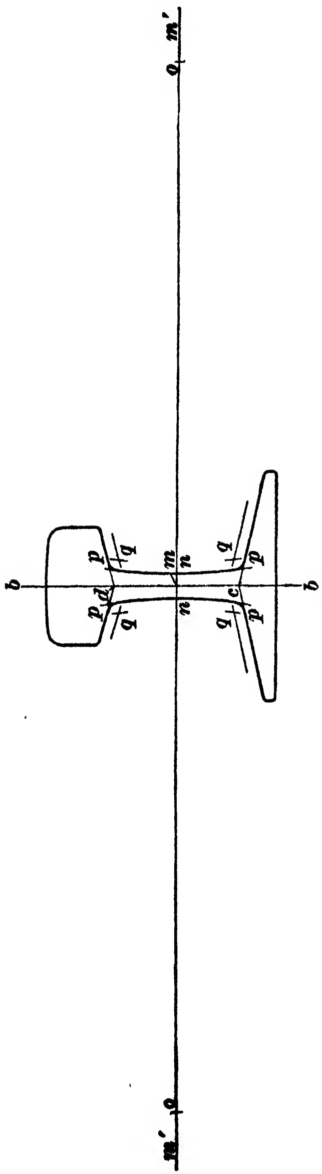


FIG. 3

6. Through the point m, Fig. 3, half way between c and d, draw the horizontal line $m' m'$, and lay off $n n$, one-half on each side of $b b$, from the thickness of web shown on the plate. Next, mark the points o on $m' m'$ at distances of 12 inches from the points n. With the points o as centers, and a radius equal to $o n$ (12 inches by scale), describe arcs p, p. These arcs intersect the sloping lines of the base and head; the corners at the intersections are rounded to curves having radii of $\frac{1}{4}$ inch. To find the centers of these curves, lay off lines parallel to the sloping lines and $\frac{1}{4}$ inch from them. With the points o as centers, and a radius of $12 - \frac{1}{4} = 11\frac{3}{4}$ inches, describe arcs intersecting the lines parallel to the sloping lines at the points q, which are the centers of the curves. With the points q as centers, and a radius of $\frac{1}{4}$ inch, the curves can be drawn. This completes the drawing of the rail section.

7. In tracing these sections, special care should be taken to make curves join smoothly, without forming sharp corners. This is a point that the beginner should take particular pains with, as sharp

corners at points where curves should be tangent to each other or to straight lines break the continuity of the outline and mar the appearance of the drawing; they usually betray either carelessness or lack of ability on the part of the draftsman, and create a very unfavorable opinion of him.

CROSS-SECTIONS OF RAILROAD ROADBEDS

8. Fig.* 4 shows the standard cross-section of a double-track railroad having a broken-stone ballast. In this type of construction, the natural surface of the ground is finished, as shown, to what is called the **subgrade.** The broken stone that is to be used for ballast is then placed on the top of the subgrade to a depth of about 12 inches. Wooden ties about 7 in. × 8 in. in cross-section, and 8 feet 6 inches long, are then laid on top of the ballast, and more broken stone is added until the top of the ballast is even with the top of the tie. **T** rails are spiked to the tops of the ties. In the drawing, the tops of the ties will be placed 5 inches below the top border line, and the center of the left-hand track will be placed 2¾ inches from the left border line. Fig.* 4 is drawn to a scale of ¼ inch to the foot.

9. The cross-section is drawn as shown in Fig. 4. First locate the lines *a a* and *b b* on the plate as described. Then measure over, from *b b*, 13 feet to scale, and draw *c c* for the center of the other track. Next, lay out the ties 7 inches deep

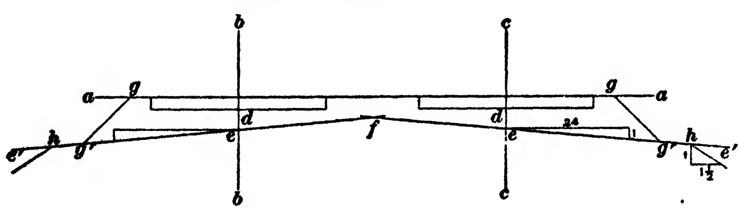


FIG. 4

and 8 feet 6 inches long, one-half on each side of the center lines *b b* and *c c*. Next, lay off *d e*, the depth of ballast, vertically below the tie, making it 12 inches. Through the points *e*, draw the lines *e e′* sloping 24 horizontal to 1 vertical;

they intersect at f. Next, locate the points g on the line $a\,a$, 1 foot beyond the ends of the ties, and draw the lines $g\,g'$, sloping 45°, to their intersections g', g' with the lines $e\,e'$. From g', g', lay off the points h, h at the edge of the subgrade, a distance of 18 inches from g', and draw the side lines sloping $1\frac{1}{2}$ horizontal to 1 vertical. This completes the cross-section, with the exception of the rails.

10. In drawing the rails to so small a scale, it is not customary to actually lay out all the dimensions, nor to go through the steps explained in Arts. **4**, **5**, and **6**. It is simply necessary to scale the width of the base and the height, which are the same, and the width of head usually about one-half the height. The remainder of the section can then be put in by eye so as to represent the actual cross-section. The standard distance between the inner surfaces of the heads is usually 4 feet $8\frac{1}{2}$ inches, as shown in Fig.* 4. This distance is called the **gauge** of the track, and the inner surfaces of the heads are called the **gauge lines** of the rails.

11. The conventional method of representing broken-stone ballast is shown in Fig.* 4, and also in Fig.* 5. It is the same in principle as that used for the representation of broken-stone concrete, except that the stones are placed close together, and the small dots representing the sand, etc. that appear in the concrete are here omitted.

12. Fig.* 5 shows a standard cross-section of a single-track railroad having broken-stone ballast. The principal difference between this cross-section and that shown in Fig.* 4 lies in the fact that, in Fig.* 5, the ballast starts to slope at the ends of the ties, and that the subgrade is level, instead of sloping as in Fig.* 4. The depth of ballast under the tie is also less, being only 10 inches. This is a somewhat cheaper construction and is well adapted for single-track railroads. The rails are shown 5 inches in height. The top of the tie is located $5\frac{7}{8}$ inches above the lower border line, and the center of the track is $4\frac{1}{4}$ inches from the left border line of the plate. Fig.* 5 is drawn to a scale of $\frac{1}{2}$ inch to the foot. The general directions given for the drawing

of Fig.* 4 apply to Fig.* 5 as well. The upper edges of the subgrade are located by measuring out 3 feet from each end of the tie and measuring down 17 inches. The points so located are connected with the ends of the tie to give the sloping surfaces of the ballast. No further instructions are necessary.

13. Fig.* 6 shows a standard cross-section of a single-track railroad with a gravel ballast. The method of representing the gravel is similar to that employed in representing gravel concrete. The top line of the tie in Fig.* 6 is $3\frac{1}{2}$ inches above the lower border line, and the center of the track is $4\frac{1}{4}$ inches from the left border line. A scale of $\frac{1}{2}$ inch to the foot is used for this figure. The slope of the subgrade is not given, but, by means of the given dimensions, the different points can be located in a manner similar to that employed in Fig.* 5. For example, the subgrade at the center of the track is 19 inches below the top of the tie; at the points where the surface of the gravel ballast intersects the subgrade, it is 27 inches lower than the top of the tie and 7 feet out from the center of the track. Outside of these points, the subgrade descends on each side with a slope of $1\frac{1}{2}$ horizontal to 1 vertical. The top surface of the gravel is rounded so as to make it level with the tops of the ties at the center of the track, and just even with the bottoms at the ends of the ties. The top curve can be put in either free-hand or with the aid of an irregular curve.

14. The student is advised to complete the tracing of Figs.* 1, 2, 3, 4, 5, and 6, together with the title, before proceeding with the pencil drawings of Figs.* 7, 8, and 9. He will thus avoid the necessity of relocating the pencil drawing on the drawing board several times, as will be necessary if he first completes the pencil drawing. This is advised because it is necessary to move the drawing paper before drawing the remainder of the plate, and it is always difficult to replace the drawing for purposes of tracing.

TIMBER TRESTLE

15. Figs.* 7, 8, and 9 represent, respectively, the top view, or plan, the side elevation, and the cross-section of a standard timber-frame railroad trestle. A frame trestle usually consists of the following parts: (1) a number of frames, called **trestle bents** or **frame bents** (Fig.* 9), set vertically, at right angles to the direction of the railroad track, and usually at equal distances apart, each bent being composed of a number of horizontal, vertical and inclined timbers; (2) a number of longitudinal timbers, called **stringers** (Fig.* 8), bolted together under each side of the track, and extending the entire length of the trestle, being placed on the top of the trestle bents and at right angles to them; (3) a top, sometimes called the **deck** or **floor** (Fig.* 7), consisting of timber cross-ties placed at equal distances apart on top of the stringers and at right angles to them, and also of longitudinal timbers, sometimes called **guard timbers,** or **ribbons,** placed on top of the ties near their ends and parallel to the direction of the track; (4) the rails, which are spiked to the tops of the ties. There are usually four rails for each track, the two outer rails being those on which the cars run, and the two inner rails, called **guard-rails,** 8 inches from the outer rails, being for the purpose of preventing a derailed car from running off the side of the trestle.

16. In representing this type of trestle, it is customary to show the three views given on this plate. In practice, it matters little which of the three views is drawn first. The dimensions given on these figures are drawn to a scale of $\frac{1}{4}$ inch to the foot. In drawing these three views, it is convenient to turn the drawing paper sidewise on the drawing board, so as to have the views upright instead of on their sides, as they appear on the plate. In referring to the border lines in the following description, the directions refer to these lines as they appear when the plate is placed sidewise on the drawing board. For example, the border line that was previously

referred to as the right border line will now be called the lower border line. It will probably be most convenient for the student to follow the figure numbers in laying out the views, that is, to draw Fig.* 7 first, then Fig.* 8, then Fig.* 9. The methods employed in laying out these views will now be explained.

17. Fig.* 7 is the top view of the top or deck, and shows, in addition to the rails, guard timbers, and cross-ties, those parts of the stringers and trestle bents that appear between and outside of the ties. The center line of the track is first laid out parallel to and $6\frac{1}{2}$ inches above the lower border line. Next, the lines representing the rails and those representing the guard timbers are put in. For the location of these lines, it is necessary to refer to Fig.* 9. The distance between the guard timbers, 8 feet, is divided by 2, and 4 feet is laid off to a scale of $\frac{1}{4}$ inch to the foot above and below the center line; the width of 8 inches locates the outside lines of the guard timbers. The distance between the gauge lines of the outside rails is given as 4 feet $8\frac{1}{2}$ inches; one-half of this is laid off on each side of the center line, and the outside edges of the guard-rails are placed 8 inches from the lines just located. The heads of the rails may be scaled $2\frac{1}{2}$ inches, and the bases, 5 inches in width. The guard timbers and rails are broken off at the left end $\frac{1}{4}$ inch, and at the right end 5 inches, from the left border line. Next, the lines representing the ties are put in; the ties are 8 inches wide and 1 foot apart center to center; so that the clear open distance between them is 4 inches. The center of the left tie shown in the figure is $\frac{1}{2}$ inch, and of the right tie $5\frac{1}{2}$ inches, from the left border line. The length of the ties is given as 10 feet, so that the ends are located 5 feet on each side of the center line. Two small circles are shown at the junction of every fourth tie with the guard timbers; they represent bolts that hold the ties and guard timbers together.

18. Next, the tops of the stringers are laid out by means of the dimensions at the right end of Fig.* 7. As shown in the figure, there are three timbers under each side of the

track, and the three timbers of each set are bolted together by long bolts. The tops of the stringers are 8 inches wide; as their centers are 9 inches apart, there is a space 1 inch wide between them. This space is provided for the purpose of allowing air to circulate between the stringers, so as to prevent decay as much as possible. At each bolt there is a cast-iron filling washer 1 inch thick placed between the stringers to keep them at the right distance apart. The ends of the stringers are shown broken off, $\frac{1}{8}$ inch and $8\frac{3}{4}$ inches from the left border line. The location of the bolts that pass through the stringers is given in Fig.* 8; it is unnecessary to reproduce to scale the exact outlines of the washer and nuts on the bolts; they may be sketched in free-hand so as to make them look like those shown on the drawing plate.

The lines representing the tops of the bents are next put in. The center of the left bent is drawn $2\frac{3}{8}$ inches, and that of the right bent, $6\frac{1}{8}$ inches from the left border line. The tops of the bents are drawn, to the scale of $\frac{1}{4}$ inch to the foot, 1 foot wide, and 12 feet long, as noted in Fig.* 9. The bracing and the bolts in the bents are not customarily shown in this view.

19. Fig.* 8 shows the side elevation of the trestle, the rails being omitted. The ties are first drawn in, the top line being located 4 inches above the lower border line and the depth made equal to 8 inches to the scale of $\frac{1}{4}$ inch to the foot. The vertical sides of the ties can be projected down from the top view, Fig.* 7. The top and bottom lines of the guard timber are next drawn in, the former 4 inches above and the latter 2 inches below the top of the ties. The stringers are then drawn, 16 inches deep, to the scale of $\frac{1}{4}$ inch to the foot, the top line being $\frac{1}{2}$ inch above the bottom line of the ties. As it is impossible to lay off a distance of $\frac{1}{2}$ inch accurately to this scale, it is sufficient to show the top of the stringers a little above the bottom of the ties. The trestle bents are next projected down from the top view and drawn 11 feet 1 inch high below the stringers, the latter being made a little shallower at the bents. In this view, the

diagonal braces on the bents are sometimes shown; in the present case, they are 3 inches in thickness.

20. Fig.* 9 shows the cross-section of the rails, guard timbers, and stringers, and the elevation of a tie and of a trestle bent. The vertical center line of the bent is $2\frac{3}{8}$ inches from the right border line. The top and bottom lines of the bent are located by projecting across from the side elevation in Fig.* 8. The top and bottom timbers are then drawn 12 inches in depth; the top timber, called the **cap**, is 12 feet in length, and the bottom timber, called the **sill**, is 16 feet in length. The center lines of the diagonal planks or **sway-braces** run from the top outer corners of the cap to the bottom outer corners of the sill. The vertical, or **plumb**, posts are next drawn, the center of each being placed 2 feet from the center line of the bent, and each being made 12 inches wide. To draw the inclined or batter posts, first locate their inner corners at the top of the sill, 5 feet on each side of the center line. Then draw their inner lines, giving them a slope of 3 inches horizontal to 1 foot vertical, and finally locate their outer lines parallel to and 12 inches from their inner lines. The posts are shown to enter the cap and sill about $\frac{1}{2}$ inch, and the ends are shown dotted, as they are invisible.

21. In making a drawing to so small a scale as $\frac{1}{48}$, or $\frac{1}{4}$ inch to the foot, the draftsman should use his judgment as to whether dotted lines to represent invisible parts should or should not be drawn. In general, they may be omitted if by so doing nothing is lost in clearness. For example, the parts of the ties that come under the guard timbers, the parts of the stringers that come under the ties, and the parts of the trestle bents that come under the stringers are not shown dotted in Fig.* 7, as the drawing sufficiently indicates the method of construction without the addition of the dotted lines. The ends of the posts in Fig.* 9 are shown dotted, however, for, if the dotted lines were omitted, there would be nothing on the drawing to indicate that the ends of the posts are to extend $\frac{1}{2}$ inch into the cap and sill.

PLATE 105, TITLE: STREETS AND PAVEMENTS

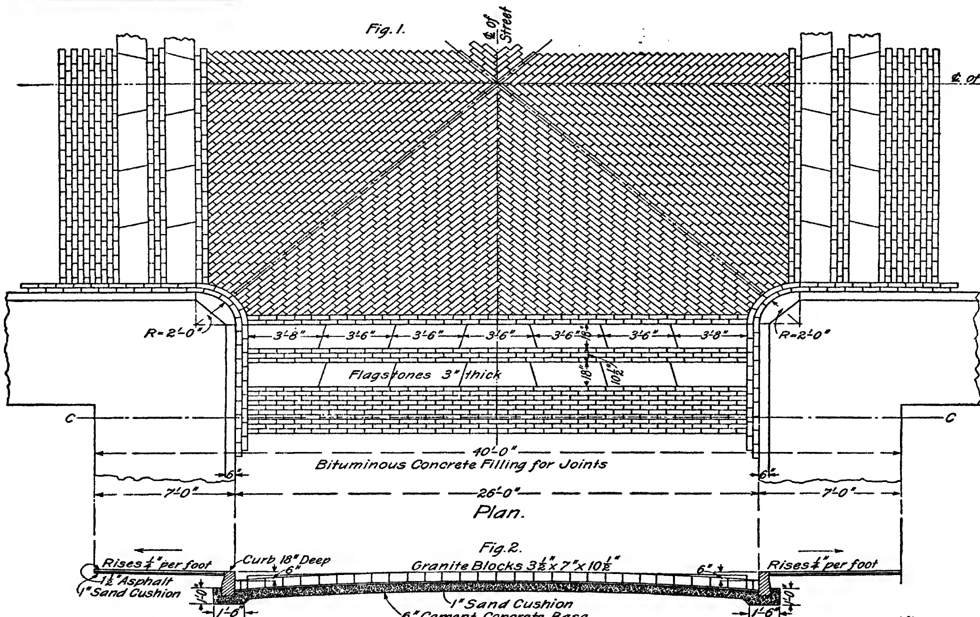
INTERSECTION OF PAVED STREETS

22. Fig.* 1 shows the plan of the intersection of two streets, and the arrangement of the sidewalks, curbstones, flagstone cross-walks, and granite-block paving stones. The total width of each street is 40 feet, divided into two sidewalks 7 feet wide and a roadway 26 feet wide between the curbs. The curbstones are shown in the plan to be 6 inches in width. At each corner where the curb lines of the streets intersect, a stone having the front edge or face curved to a radius of 2 feet for an angle of 90° is placed to connect the curb lines. The curved corner is preferable to a square corner, as the former gives a little more room for traffic and presents a better appearance.

An outside edge of each cross-walk is shown in line with the face of the curved corner stone, so as to locate it on the drawing. Each flagstone is 18 inches wide, and the distance between the lines of stones in each cross-walk is 10½ inches. The joints between each two consecutive stones in each cross-walk are beveled or skewed 3 inches to the foot, so that wagon wheels crossing them will run across and not along the joints. The ends of the flagstones are 7 inches from the faces of the curbstones; the centers of the beveled joints are located as shown on one line of stones. It is customary to lay these flagstones in lengths of from 3 to 5 feet.

The paving stones are 3½ inches wide and 10½ inches long, and at the intersection are laid diagonally so as to have the traffic cross the stones instead of running parallel to the long joints, thereby wearing deep ruts and destroying the pavement. When the paving blocks are laid as shown, the wheels of wagons passing along either street cross the long joints at an angle, while the wheels of wagons that turn the corners cross the stones nearly at right angles. In the drawing, there are two lines of paving blocks parallel to the curb, two lines parallel to the cross-walks on the sides toward the

Fig. 1.



Plan.

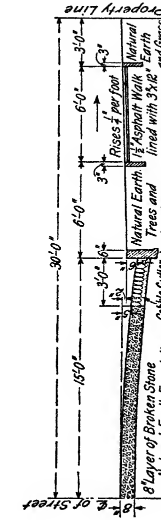
Fig. 2.

Cross Section on C–C

Intersection of Business Streets Paved with Granite Blocks

Cross Section of Business Street Paved with Asphalt

Fig. 3.



½ Cross Section of 60' Residence Street with Macadam Roadway and Asphalt Sidewalk.

Fig. 4.

STREETS AND PAVEMENTS

DRAWN BY ....
DATE ....

105

surface. The curbstone is 18 inches deep, about 6 inches thick, and its lower end is embedded in cement concrete about 6 inches in thickness on each side and under the curbstone. The granite blocks are shown 7 inches in depth; their top surface at the center of the street is level with the top of the curbstone, and at the edges it is 6 inches below the top of the curbstone. Under the granite blocks there is first a layer of sand 1 inch in thickness, and under this a layer of cement concrete 6 inches in thickness. The ends of the flagstones are 3 inches higher than the top of the granite blocks, and at 6 feet from the curb are level with the blocks.

25. To lay out this figure on the pencil drawing, first draw a line parallel to the lower border line and 4 inches above it. Let this be the level of the top of the curb and the center of the road. From the plan shown in Fig.* 1, project down the location of the street lines, the outer and inner surface of the curbstones, and the joints between the blocks. Next, draw the top lines of the sidewalks, making them rise toward the street lines $\frac{1}{4}$ inch per foot, that is, 1 vertical to 48 horizontal, and two lines parallel to each of them to represent the lower surface of the asphalt and the lower surface of the sand cushion. Then, measure down 6 inches from the top of the curbstone at each side, and draw in the curved line representing the top surface of the roadway. The bottom of the paving blocks and the top and bottom of the concrete foundation are then drawn in parallel to the curved top of the paving blocks. The ends of the cross-walk are then shown 3 inches above the roadway, and the top line is drawn. Next, draw the sides and bottom of the curbstones, and show the concrete 6 inches thick around the bases.

CROSS-SECTION OF ASPHALT PAVEMENT

26. Fig.* 3 shows a cross-section of a street 40 feet wide arranged in the same way as that shown in Fig.* 2, except that in the former the wearing surface is asphalt, while in

the latter it is composed of granite blocks. The top of the roadway at the center is shown level with the tops of the curbs, and the gutters are 6 inches below the top of the curbs. In this cross-section, the curbstones are not set in concrete, but the concrete of the foundation extends to the bottom of the stones, having this depth for a distance of 1 foot 6 inches out from each curb, as shown.

27. To lay out this figure, first draw a line parallel to and $1\frac{3}{4}$ inches from the lower border line. Let this be the top of the curbstones and the top of the roadway at the center. Next, locate the street lines and curbstones in the same way as for Fig.* 2. The remainder of the figure is drawn in the same way as Fig.* 2, and should present no difficulty.

28. In drawing this plate, the student is advised to complete the tracing of Figs.* 1, 2, and 3, and the title, before turning the pencil drawing around to work on Fig.* 4. In describing this last figure, the border lines will be referred to as they appear when the drawing is placed sidewise on the drawing board. For example, the border line that is on the right when the drawing is upright on the board will be the lower border line when the drawing is placed sidewise.

CROSS-SECTION OF MACADAMIZED ROADWAY

29. Fig.* 4 is the cross-section of one-half of a residence street 60 feet in width. The roadway is 30 feet in width, and is paved with broken stone 8 inches in thickness. For a width of 3 feet at each side there are cobblestones about 6 inches in depth, resting on a foundation or bed of sand 2 inches in thickness. The outer edge of the gutter is 5 inches below the center of the street; the inner edge of the gutter next to the curbstone is 8 inches below the center of the street, and the top of the curbstone is 6 inches above the gutter, or 2 inches below the center of the street. The curbstone is 6 inches wide and 18 inches deep, and the sidewalk rises $\frac{1}{4}$ inch per foot from the top of the curbstone

toward the street line. The sidewalk is divided into three parts: the outer, 6 feet in width, is for trees and shrubbery; the inner, 3 feet in width, is for grass; the middle, 6 feet in width, is paved with asphalt, and lined on each side with edge stones 3 inches in width and 12 inches in depth, to protect the edges of the asphalt.

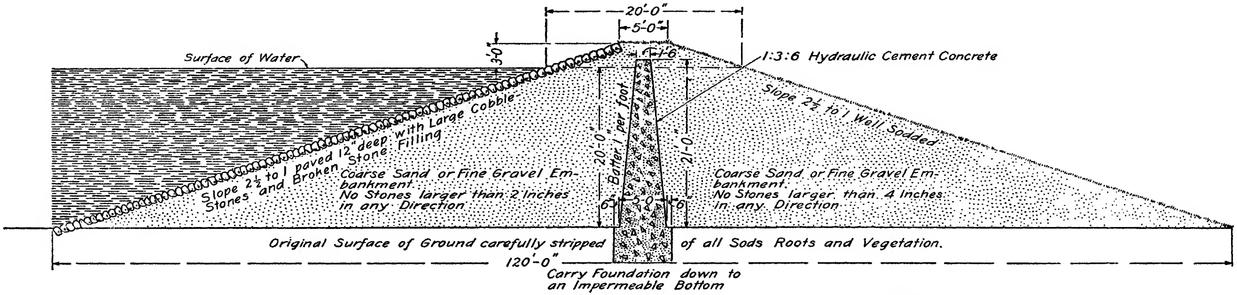
30. To lay out this figure on the drawing, first draw a line parallel to and $2\frac{1}{4}$ inches from the lower border line. Let this line be level with the top of the curb. Locate a point on this line $5\frac{3}{4}$ inches from the right border line; let this be the outside corner of the curbstone. Next, locate the center of the street, the outer edge of the gutter, the outer and inner edges of the sidewalk, and the street line, by laying out the distances given on the plate to a scale of $\frac{1}{4}$ inch to the foot. Next, draw in the top of the roadway, gutter, and sidewalk. The remainder of the lines can then be drawn in much the same way as for Figs.* 2 and 3.

PLATE 106, TITLE: DAMS AND PIPES

EARTH DAM WITH CONCRETE CENTER WALL

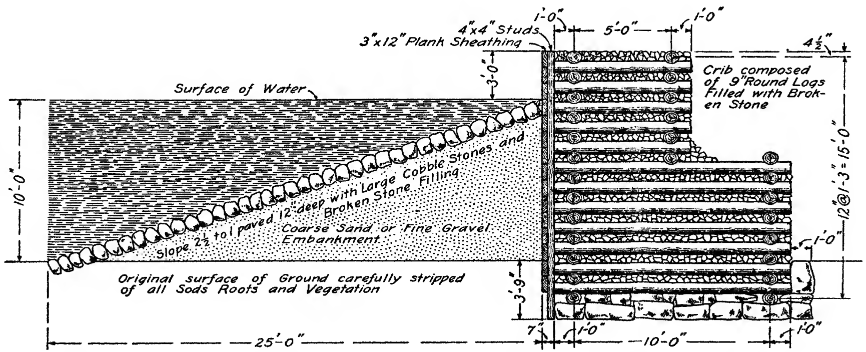
31. Fig.* 1 is a cross-section of an earth dam with a concrete center wall. This wall serves the purpose of preventing water from percolating through the dam and washing out the filling material. The center wall usually extends a short distance above high-water level and is carried down into material that does not allow water to pass through; this prevents the water from percolating under the center wall and undermining it. The filling material is carried up 2 or 3 feet above the top of the wall, and is finished off flat on top.

The slopes of the top surfaces of the embankment depend somewhat on the amount of room available and on the material used: they are seldom made steeper than those shown on the plate, that is, $2\frac{1}{2}$ horizontal to 1 vertical. The inner slope is paved with stone to prevent the filling material



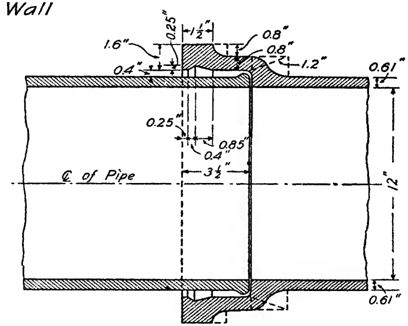
Cross-Section of Earth Dam with Concrete Center Wall

Fig. 1.



Cross-Section of Timber Crib Rock Fill Dam with Earth Embankment

Fig. 2.



Cross-Section of Bell and Spigot Joint for 12" Cast Iron Pipe

Fig. 3.

DAMS AND PIPES

DRAWN BY________
DATE________

106

from washing away. The outer slope is sodded to protect it against erosion by rain.

32. In making a complete working drawing of an earth dam, it is necessary to show a plan, an elevation, and several cross-sections. The cross-sections are taken at different points along the dam—near the ends, through the spillway, and at intermediate points. All views that help to illustrate the work and direct the workmen are shown on the drawings, and, as far as possible, all the dimensions are also shown. When it is simply desired to illustrate the general type of construction, it is sufficient to show one cross-section taken at an intermediate point in the length of the dam, where there are no special features, such as a spillway. This is the plan followed in Fig.* 1.

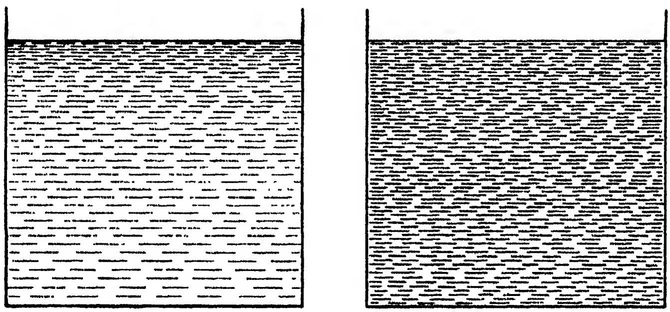
33. To lay out the cross-section, first draw the center line of the center wall vertically in the center of the plate. Next, draw a horizontal line parallel to and 4 inches from the top border line. Let this be the bottom of the embankment. Next, lay off the different dimensions given on the sheet, to a scale of $\frac{1}{8}$ inch to the foot.

The footing of the center wall is 6 feet wide, and has vertical sides extending up to the bottom of the embankment. At that height, the concrete is set in 6 inches at each side, and the faces of the wall rise to a height of 21 feet above the bottom of the embankment, each face being battered 1 inch per foot. Since both faces are battered, the faces approach each other 2 inches per foot, or $21 \times 2 = 42$ inches = 3 feet 6 inches in the height of this portion, making the top width 5 feet minus 3 feet 6 inches, or 1 foot 6 inches. The section of the center wall is filled with the conventional sign for broken-stone concrete. The top of the embankment is now located 2 feet above the top of the wall, and the level part is made 5 feet in width, one-half on each side of the center line. The side slopes are now put in with a batter or slope of $2\frac{1}{2}$ horizontal to 1 vertical. Since both surfaces slope, the width of the embankment increases 5 feet for every foot of depth; and, as the height is $20 + 3 = 23$ feet and the top width is

5 feet, the bottom width is $(5 \times 23) + 5 = 120$ feet. The surface of the water can now be located 20 feet above the bottom of the embankment.

34. The stones on the water side of the dam are sketched in freehand. To represent the filling material, small dots are placed all over the section of the embankment, except where lettering occurs.

35. There are two methods of representing water in cross-section. They are shown in Fig. 5: in that shown in (*a*), the top lines are heavier and closer together than



(*a*) Fig. 5 (*b*)

those lower down; in that shown in (*b*), the lines are all the same weight and the same distance apart. The student is advised to practice both methods; he may use whichever he prefers.

TIMBER-CRIB ROCK-FILL DAM

36. Fig.* 2 shows the cross-section of a timber-crib rock-fill dam. A dam of this kind is composed of a crib of logs built up as shown and filled in with broken stone and rocks to give the structure greater stability. Vertical studs, about 4 in. × 4 in., are attached to the ends of the logs, and 3-inch sheathing is spiked to them to keep the water from leaking through. An embankment is built up on the water side in the same manner as described in Fig.* 1. This dam is much smaller than that shown in Fig.* 1, and is drawn to a scale of $\frac{1}{4}$ inch to the foot.

37. To draw the figure, first draw a vertical line parallel to and $7\frac{1}{4}$ inches from the left border line. Let this be the front of the sheathing. Next, draw a horizontal line parallel to and $2\frac{5}{8}$ inches from the lower border line. Let this line be the bottom of the filling material. Next, locate the surface of the water 10 feet above the bottom of the embankment, and draw the top line of the slope from the intersection of the water surface with the face of the sheathing, with a slope of $2\frac{1}{2}$ horizontal to 1 vertical. Since the top of the slope is 10 feet above the bottom of the embankment, the bottom is $10 \times 2.5 = 25$ feet from the face of the sheathing. The cobblestone paving on the slope can now be sketched in, and the triangular section of the embankment dotted all over to represent the filling.

Next, draw two vertical lines to represent the two sides of the vertical studs to which the sheathing is attached. Locate the top of the stud 3 feet above, and the bottom, 13 feet 9 inches below, the surface of the water. Beginning at the top of the stud, mark off 15 sheathing boards, each 12 inches in width. Next, draw a vertical construction line 12 inches from the back of the stud and locate the centers of the logs on it. The center of the top log, shown in cross-section, is $4\frac{1}{2}$ inches below the top of the stud; the remaining logs are spaced 15 inches apart from center to center. The logs shown horizontal are half way between the others; the five upper ones are 7 feet long and the seven lower ones are 12 feet long. Next, locate the other vertical rows of logs 5 feet and 10 feet back of the front row, and mark the centers. The logs can now be drawn in, and the spaces between them filled with broken stone. Next, draw in the foundation stones, making them extend 3 feet 9 inches below the bottom of the embankment and 12 inches beyond the end of the logs.

The lines representing the grain of the wood are put in freehand after the remainder of the drawing is finished.

CAST-IRON PIPE JOINT

38. Fig.* 3 shows the cross-section of a bell-and-spigot joint for a 12-inch cast-iron pipe. The dimensions shown in the figure are drawn to a scale of 3 inches to the foot. To draw this figure, first draw the horizontal center line parallel to and $4\frac{7}{8}$ inches from the lower border line. Next, locate the end of the spigot end inside of the bell, $2\frac{1}{4}$ inches from the right border line. Then, lay off to scale the diameter of the pipe, and the thickness of each side. The thickness is given as .61 inch, which is a decimal fraction. In such cases, it is convenient to transform first the decimal into an equivalent common fraction. In the present case, it is sufficiently accurate to scale the thickness as $\frac{5}{8}$ inch. The beaded end of the spigot can now be drawn. The detail of this end is shown in Fig. 6.

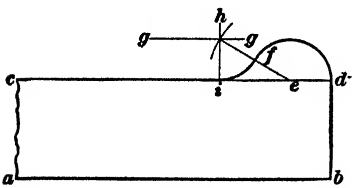


FIG. 6

The line $a\,b$ is the inside and the line $c\,d$ the outside of the pipe. The point e is located $\frac{1}{4}$ inch from d, and the arc $d\,f$ is

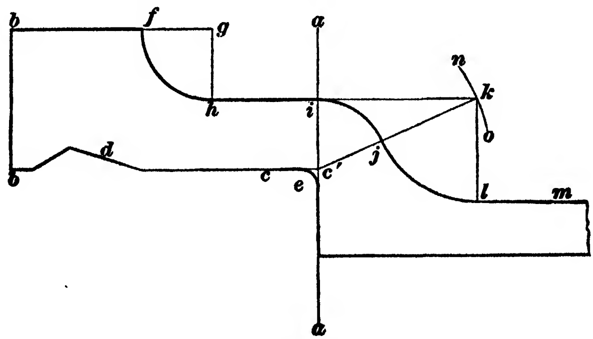


FIG. 7

drawn with a radius of $\frac{1}{4}$ inch and center at e. The line $g\,g$ is then drawn parallel to $c\,d$ and $\frac{1}{4}$ inch from it. The point h is located by swinging an arc with a radius of $\frac{1}{2}$ inch about e as a center, until it intersects $g\,g$. With h as a center, and a radius of $\frac{1}{4}$ inch, the arc $i\,f$ is drawn; this completes this end of the pipe.

Next, draw the inside line of the bell *a a*, Fig. 7, parallel to and very close to the vertical end of the pipe already drawn, and locate the left end *b b* of the bell $3\frac{1}{2}$ inches to the left of the inside line.

Now, draw a horizontal line *b c* representing the inside of the bell, parallel to and .4 inch from the outside of the spigot end, and locate the groove *d* according to the dimensions shown in Fig.* 3. The inner corner *e* of the bell is slightly rounded freehand where the horizontal line *b c* meets the vertical *a a*. Next, locate the outer ring *b f* of the bell, 2 inches from the outside of the shell of the pipe, and make it $1\frac{1}{2}$ inches in width. Continue *b f* to *g*, a distance of .8 inch (nearly $\frac{13}{16}$ inch); and, with *g* as a center, and a radius of .8 inch, describe the arc *f h*, turning through 90°. Draw the line *h i* to its intersection with *a a*. With the point *c'*, the intersection of *b c* and *a a*, as a center, and a radius of .8 inch, describe the arc *i j*; with *c'* as a center, and a radius of $.8 + 1.2 = 2$ inches, describe the short arc *n o*, and locate the point *k* on it at a distance of 1.2 inches from *l m*, the outside of the shell of the pipe. With *k* as a center, and 1.2 inches as a radius, describe the arc *j l*. The section of the pipe can now be cross-hatched or section-lined by means of the ruling pen and triangle, spacing the triangle by hand. This completes the drawing of the bell.

A SERIES OF QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME

It will be noticed that the Examination Questions that follow have been divided into sections, which have been given the same numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until that portion of the text having the same section number as the section in which the questions or examples occur has been carefully studied.

THE TRANSITION SPIRAL

EXAMINATION QUESTIONS

(1) On a certain stretch of track there are three circular curves whose degrees of curve are 3°, 5°, and 7° 30′, respectively. Find, by Table I, the superelevation of the outer rail for each curve, if a speed of 50 miles per hour is to be allowed for.

Ans. $\begin{cases} .427 \text{ ft. for the } 3° \text{ curve} \\ .707 \text{ ft. for the } 5° \text{ curve} \\ 1.046 \text{ ft. for the } 7° \ 30' \text{ curve} \end{cases}$

(2) The superelevation of a 4° circular curve is .5 foot. Would it be safe for a train to run over this curve with a velocity of 60 miles per hour?

(3) A spiral 300 feet long connects with a 10° curve. Find the degree of curve of spiral at points 75 feet apart on the spiral.

Ans. $\begin{cases} \text{At first stake, } 2° \ 30' \\ \text{At second stake, } 5° \ 00' \\ \text{At third stake, } 7° \ 30' \\ \text{At P. S, } 10° \ 00' \end{cases}$

(4) In question 3, find the superelevation of the outer rail at each stake, if a train speed of 40 miles per hour is to be allowed for. Solve this question both by Table I and by the formula of Art. **13**.

Ans. By formula $\begin{cases} \text{At first stake, .225 ft.} \\ \text{At second stake, .449 ft.} \\ \text{At third stake, .674 ft.} \end{cases}$

(5) A spiral 500 feet long connects with a 4° circular

curve. Find, by the tables, the deviation and deflection angles to stakes 100 feet apart on the spiral.

Ans. $\begin{cases} \text{At first stake, } \delta = 0° \ 24', \theta = 0° \ 8' \\ \text{At second stake, } \delta = 1° \ 36', \theta = 32' \\ \text{At third stake, } \delta = 3° \ 36', \theta = 1° \ 12' \\ \text{At fourth stake, } \delta = 6° \ 24', \theta = 2° \ 8' \\ \text{At P. S., } \delta = 10° \ 0', \theta = 3° \ 20' \end{cases}$

(6) In the spiral of the preceding question, the transit was moved forwards to a point 360 feet from the P. S_1, and a backsight taken on the P. S_1. Find the angle that must be deflected from this direction to bring the telescope tangent to the spiral at this point. Ans. 3° 27.6′

(7) A spiral 600 feet long connects with a 3° curve. Find: (*a*) the distance *CR*, Fig. 8, and (*b*) the offset *PR* to a point on the spiral 540 feet from the P. S_1.

Ans. $\begin{cases} (a) \ 539.13 \text{ ft.} \\ (b) \ 22.91 \text{ ft.} \end{cases}$

(8) If, in the preceding question, the length of the spiral is 500 feet, find: (*a*) the distance *CV*, Fig. 8; (*b*) the spiral offset *VE*; and (*c*) the offset *KM′* to the middle point of the spiral.

Ans. $\begin{cases} (a) \ 249.90 \text{ ft.} \\ (b) \ 4.54 \text{ ft.} \\ (c) \ 2.27 \text{ ft.} \end{cases}$

(9) Two spirals, each 200 feet long, connect with a 4° circular curve. The angle between the tangents is 108°. Find the distance from the point of intersection of the tangents to the P. S_1 of either spiral. Ans. 2,073.3 ft.

(10) In the preceding question, find: (*a*) the central angle *VOA* = *V′OB*, Fig. 11, of each spiral; (*b*) the central angle *AOB* of the circular curve.

Ans. $\begin{cases} (a) \ 4° \\ (b) \ 100° \end{cases}$

(11) If the station number of the point of intersection of the tangents in questions 9 and 10 is 401 + 88.3, find the station number of each P. S_1 and each P. S_2.

Ans. $\begin{cases} \text{P. } S_1 = 381 + 15, A = 383 + 15, \\ B = 408 + 15, \text{P. } S_1' = 410 + 15 \end{cases}$

(12) Compute the necessary angles for laying out in the field the curve and spirals of question 9, and fully describe the field work if the method of Art. 25 is to be employed. The stakes are to be set 50 feet apart on each spiral, and at the regular stations on the circular curve.

(13) In question 9, find the external distance to the spiraled circular curve. Ans. 1,006.8 ft.

(14) If a new circular curve of 6° has been chosen, what length of spiral will produce a throw of 2.8 feet at the new P. C.? Ans. 360 ft., nearly

(15) Two tangents that intersect at an angle of 60° 40′ are connected with an unspiraled 8° circular curve. It is desired to replace this with a new circular curve and spirals in such a manner that the track may be moved as little as possible on the roadbed. Assuming that a throw of 2 feet is allowable at the vertex and at the new P. C., determine: (*a*) the degree of curve; (*b*) the length of spiral.

Ans. $\begin{cases} (a) & 8^\circ\ 30' \\ (b) & 254 \text{ ft.} \end{cases}$

(16) Solve the preceding question, if a throw of 2 feet is allowable at the new P. C. but the vertex of the old curve must not be moved.

Ans. $\begin{cases} D = 8^\circ\ 20' \\ L = 257 \text{ ft.} \end{cases}$

(17) Find: (*a*) the best length of spiral to connect with a 5° curve, if a speed of 50 miles per hour is to be allowed for; (*b*) the least length that it is desirable to select for the spiral, unless the topographical conditions render a still shorter length necessary.

Ans. $\begin{cases} (a) & 578.7 \text{ ft.} \\ (b) & 500 \text{ ft.} \end{cases}$

EARTHWORK

EXAMINATION QUESTIONS

(1) In an earthwork survey, the elevations of the natural surface of the ground at the successive stations are as follows: Sta. 21, 162.3; Sta. 22, 160.4; Sta. 23, 158.7; Sta. 24, 160.0; Sta. 24 + 40, 157.9; Sta. 25, 162.4; Sta. 26, 162.7, and Sta. 27, 164.5. Elevation of subgrade at Sta. 21 = 164.60. The gradient is − 1.3% from Sta. 21 to Sta. 24 and + .6% beyond Sta. 4. Find the center depth at each stake.

	Station	Center Depth, in Feet
Ans.	21	F 2.3
	22	F 2.9
	23	F 3.3
	24	F 0.7
	24 + 40	F 3.0
	25	C 1.1
	26	C .8
	27	C 2.0

(2) Solve the preceding question if the gradient is + 1.1% from Sta. 21 to Sta. 24 + 40, and + 1.6% beyond Sta. 24 + 40, the elevation of subgrade at Sta. 21 being 157.14.

	Station	Center Depth in Feet
Ans.	21	C 5.2
	22	C 2.2
	23	F .6
	24	F 0.4
	24 + 40	F 3.0
	25	C .6
	26	F .7
	27	F .5

(3) In setting slope stakes for a cut, the reading on the rod at the center stake is 5.3, the reading at a point 28 feet from the center stake is 1.3, and the depth of the center stake is 4.1 feet. If the roadbed is 22 feet wide and the slope ratio is 2 : 1, should the trial point be moved out or in?
Ans. The trial point should be moved in

(4) The rod reading for setting the other slope stake in the preceding question is 7.8, and the distance from the rod to the center line is 13.5 feet. Should this point be moved out or in? Ans. The trial point should be moved out

(5) One end of a triangular prismoid is a triangle whose base is 20 feet and whose altitude is 10 feet; the other end is a triangle whose base is 5 feet and whose altitude is 7 feet. If the prismoid is 100 feet long, find its volume, applying the prismoidal correction. Ans. 204 cu. yd.

(6) Find, from the following notes and using the average-end-area method, the volume V_1 of the prismoid between Sta. 20 and Sta. 21 + 30, the slope being $1\frac{1}{2} : 1$, and the roadbed being 24 feet wide.

Station	Center Depth	Left	Right
21 + 30	C 6.8	$\frac{C\ 11.4}{29.1}$	$\frac{C\ 4.0}{18.0}$
21	C 5.0	$\frac{C\ 10.8}{28.2}$	$\frac{C\ 3.4}{17.1}$
20	C 1.0	$\frac{C\ 4.0}{18.0}$	$\frac{C\ .1}{12.1}$

Ans. $V_1 = 690$ cu. yd.

(7) Solve example 2 of Art. **25** by the method of Art. **26**, and tabulate the work as in Art. **28**, obtaining only the volume V_1. Ans. $V_1 = 426$ cu. yd.

(8) Compute the prismoidal correction for the notes of question 6, and obtain the volume V between Sta. 20

and Sta. 21 + 30. Arrange the computation as shown in Art. **25.**

Ans. $\begin{cases} C = -19 \text{ cu. yd.} \\ V = 671 \text{ cu. yd.} \end{cases}$

(9) From the following notes, find the volume V of cut between Sta. 100 and Sta. 101, the roadbed being 20 feet wide in the cuts and 16 feet wide in the fills.

Station	Center Depth	Left	Right
101	C 1.3	$\frac{F\ 10.0}{28.0}$ $\frac{0}{3.3}$	$\frac{C\ 20.1}{50.2}$
100	F 1.8	$\frac{F\ 16.2}{40.4}$	$\frac{0}{5.0}$ $\frac{C\ 8.0}{26.0}$ $\frac{C\ 10.2}{30.4}$

Ans. V = 260 cu. yd.

(10) Compute the volume V of the fill in the preceding question. Ans. V = 223 cu. yd.

(11) If the cut in question 6 is on a 12° curve to the left, compute the correction of the volume for curvature.

Ans. C_c = 8 cu. yd.

(12) Compute the correction for curvature for the fill of question 9, if the center line of the roadbed is an 8° curve to the left. Ans. C_c = 5 cu. yd.

(13) How many cubic yards of embankment can be made from the material excavated in the cut of question 8, if the material is of a sandy character? Ans. 617 cu. yd.

RAILROAD LOCATION

EXAMINATION QUESTIONS

(1) What are the primary considerations that govern the choice of a route for a railroad?

(2) What is a train-mile, and for what is this unit used?

(3) What elements of construction and operation must be considered in comparing the relative value of two proposed routes?

(4) (*a*) What is the essential nature of a reconnaissance survey? (*b*) What data should be obtained?

(5) (*a*) How are routes classified, according to topographical conditions? (*b*) What are the characteristic difficulties of each route?

(6) Describe the various methods for obtaining a low grade in a very mountainous country.

(7) What is the essential nature and purpose of a preliminary survey?

(8) (*a*) How closely should leveling be done in a preliminary railroad survey? (*b*) Why is closer work useless?

(9) What is the general method of estimating earthwork from preliminary surveys?

(10) What is the essential difference between a preliminary and a location survey?

(11) How are the results of the preliminary survey utilized in projecting the location?

(12) State briefly the outlines of the best method of making a location in a very mountainous country.

(13) What principle should be followed regarding the limitation of sharp curvature?

(14) (*a*) What is curve compensation? (*b*) What rate of compensation is usually employed?

(15) If the maximum gradient on tangents is 1 per cent., what will be the maximum gradient on a 7° curve, allowing a compensation of .04 foot per degree?

(16) The maximum gradient on tangents is 2 per cent.; what is the maximum gradient on an 8° curve, allowing a compensation of .04 foot per degree?

(17) If the following pairs of intersecting grade lines have the gradients indicated, tell in each of the six cases whether a sag or a spur will occur at the intersection: (*a*) +1 per cent. and +1.4 per cent.; (*b*) +1.3 per cent. and +.2 per cent.; (*c*) +1 per cent. and −.2 per cent.; (*d*) −1.3 per cent. and −1 per cent.; (*e*) −.6 per cent. and −1.1 per cent.; (*f*) −1.8 per cent. and +.6 per cent.

(18) A +1.2-per-cent. grade meets a −.4-per-cent. grade, the elevation of the point of intersection being 333.41 feet. If a vertical curve 400 feet long is inserted, find the corrected elevations of stakes 50 feet apart on the curve. Table II cannot be used in this case.

(19) If a −1.6-per-cent. grade meets a −.6-per-cent. grade, select the vertical curve and find the corrected elevations of stakes 50 feet apart, the elevation of the point of intersection being 50.60 feet. Use Table II.

TRESTLES

EXAMINATION QUESTIONS

(1) What are the advantages and disadvantages of using wooden trestles rather than earth embankments?

(2) If earth work costs 20 cents per cubic yard, and a framed trestle costs \$35 per M., B. M., which would be the more expensive: an embankment with a roadbed 14 feet wide, slope $1\frac{1}{2} : 1$, and an average height of 20 feet, or a framed trestle of the same average height?

(3) What is the maximum economical height for pile trestles, and why?

(4) Describe and illustrate the several methods for fastening caps to the tops of piles.

(5) What are the advantages and disadvantages in the use of drift bolts?

(6) (*a*) Why are stringers made up of several pieces? (*b*) Why are separators or packing-blocks used between parallel stringers? (*c*) What are jack-stringers, and why are they used?

(7) How are ties secured to the stringers on trestles?

(8) What are the usual dimensions of guard-rails, and how are they fastened together and to the ties?

(9) (*a*) What are sway-braces? (*b*) What are their usual dimensions? (*c*) How are they fastened to the trestle bents?

(10) What is the usual method of guarding against longitudinal stresses in trestles?

(11) State the method you prefer for elevating the outer rail on curves on trestles, and give your reasons for your preference.

(12) What are dowels and how are they used?

(13) (*a*) What are lagscrews? (*b*) For what purposes are they employed in trestle building?

(14) (*a*) What is a refuge bay? (*b*) How is it constructed?

(15) What practical means are adopted for protecting trestles from fire?

(16) How much land should be cleared and grubbed before erecting a trestle?

(17) What method is adopted in paying for piling work done by a contractor?

(18) What treatment is given to creosoted timber used in trestle work at the places where cutting and trimming is necessary during construction?

TRACKWORK

(PART 1)

EXAMINATION QUESTIONS

(1) (*a*) What is the best kind of ballast, and why? (*b*) Describe the form that a roadbed should have when this kind of ballast is used for double track.

(2) (*a*) Which is the better tie, chestnut or walnut? (*b*) What is the principal cause of failure of cedar and cypress ties? (*c*) How may it be partly overcome?

(3) On a prairie road, it was found that oak ties would cost 80 cents each, and tamarack ties, 22 cents. The latter may be vulcanized at 25 cents per tie, and furnished with tie-plates at 18 cents a pair. Find which will be the cheaper per mile of track and how much, if the spacing of the oak ties is $2\frac{1}{4}$ feet, and of the tamarack ties 2 feet, and 10 per cent. is added to the cost of the oak ties for transportation.

(4) The total weight on the eight drivers of a locomotive is 120,000 pounds. Find the necessary weight of rail per yard.

$$\text{Ans.}\begin{cases}\text{By the rule of Art. } \mathbf{20}\text{, 67 lb.}\\ \text{By the rule of Art. } \mathbf{21}\text{, 60 lb.}\end{cases}$$

(5) Describe nut-locks, and explain how they prevent the nuts from working loose.

(6) A track is laid with 50-pound rails that average 28 feet in length; patented angle bars are employed that require six bolts each and cost $1.60 per pair, the bolts being $\frac{5}{8}$ in. $\times$ 4 in.; the ties are spaced 2 feet apart. Find the cost

of the rails per mile of track, at $30 per ton, allowing 2 per cent. for waste. Ans. $2,404.24

(7) Find the cost, per mile of track, of the angle bars in question 6. Ans. $603.20

(8) Find the cost, per mile of track, of the bolts in question 6, at 2.4 cents per pound. Ans. $35.60

(9) Find the cost, per mile of track, of the spikes in question 6, at 1.6 cents per pound. Ans. $82.72

(10) Find the space to be allowed between the rails for expansion when track is being laid at a temperature of 50°: (*a*) if the rails are 30 feet long; (*b*) if the rails are 40 feet long. Ans. $\begin{cases}(a) \ \frac{3}{16} \text{ in.} \\ (b) \ \frac{1}{4} \text{ in.}\end{cases}$

(11) Find the difference in length between the inner and outer rails of a 5° curve 960 feet long. Ans. 4.125 ft.

(12) Find: (*a*) the middle, and (*b*) the quarter ordinates to curved rails, 30 feet long, if the degree of curve is 4°.

Ans. $\begin{cases}(a) \ \frac{15}{16} \text{ in.} \\ (b) \ \frac{45}{64} \text{ in.}\end{cases}$

(13) Find the increase of gauge for an 8° curve.

Ans. $\frac{1}{2}$ in.

(14) Find the distance from the gauge rail to the guard-rail for a 4° curve. Ans. $2\frac{1}{8}$ in.

(15) Find the amount of ballast required to fill up a sag in the track, if the depth of the sag is .9 foot, and the length 300 feet, and the embankment is 15 feet wide.

Ans. 75 cu. yd.

TRACKWORK

(PART 2)

EXAMINATION QUESTIONS

(1) Find the frog angle of a No. 5 frog.

Ans. 11° 25′ 16″

(2) The angle between the center lines of two intersecting straight tracks is 14° 15′. What number of frog will be required? Ans. 4

(3) To determine the number of frog, the distance *s h*, Fig. 9, was measured and found to be 8 feet; the heel width *a b* is 16 inches, and the mouth width *d e* is 8 inches. What is the frog number? Ans. 4

(4) Find the radius of a turnout from a straight track for a No. 11.5 frog, if a stub switch is to be employed.

Ans. 1,245.3 ft.

(5) Find the lead in the turnout of question 4.

Ans. 108.28 ft.

(6) If the throw of a stub switch is $5\frac{1}{2}$ inches and the radius of the center line of the turnout is 680.36 feet, find the length of the switch rails, (*a*) by direct calculation, (*b*) from Table II.

Ans. $\begin{cases} (a) \ 24.97 \text{ ft.} \\ (b) \ 24.93 \text{ ft.} \end{cases}$

(7) Find, from Table II, the dimensions of a stub switch if a No. 9 frog is employed.

Ans. $\begin{cases} L = 84.75,\ r = 762.75,\ l = 26.43,\ Ka = 3.37, \\ AK = 58.32, \text{ and } Aa = 54.95 \text{ ft.} \end{cases}$

(8) Find, from Table III, the dimensions of a point-switch turnout if a No. 9 frog is employed.

Ans. $\begin{cases} S = 1^\circ\ 50',\ L = 72.20,\ l = 15.0,\ Ka = 3.37,\ BK \\ = 57.20,\ Ba = 53.83,\ r = 681.16, \text{ and } d = 8^\circ\ 25' \end{cases}$

(9) From a curve of the main track whose degree of curve is 3° 30′, a turnout is to be laid to the outside of the main-track curve, a No. 9 frog being employed. Find the lead of the turnout and the degree of curve of its center line for a point switch. Ans. $\begin{cases} \text{Degree of curve of turnout} = 4^\circ\ 55' \\ L = 72.20 \text{ ft.} \end{cases}$

(10) From a curve of the main track whose degree of curve is 5°, a turnout is to be laid to the inside of the main-track curve, a No. 6 frog being employed. Find the lead of the turnout and the degree of curve of its center line for a point switch. Ans. $\begin{cases} \text{Degree of curve of turnout} = 24^\circ\ 59' \\ L = 56 \text{ ft.} \end{cases}$

(11) Find the radius of the connecting curve and the distance KT, Fig. 19, for two parallel straight tracks 13 feet apart, if a No. 5 frog is employed. Ans. $\begin{cases} r' = 421.10 \text{ ft.} \\ KT = 82.92 \text{ ft.} \end{cases}$

(12) A siding is to be laid to the outside of a 4° 30′ main-track curve, the distance between the center lines of the siding and main track being 13 feet. If a No. 8 frog is employed, find the radius of the connecting curve and the distance KT, Fig. 20. Ans. $\begin{cases} r = 584.92 \text{ ft.} \\ KT = 132.07 \text{ ft.} \end{cases}$

(13) If the center lines of two parallel straight tracks are 13 feet apart, compute the dimensions of a cross-over between them, if a No. 7 frog and a reverse-curve cross-over are inserted, a stub switch being employed.

Ans. $\begin{cases} BK = 65.92 \text{ ft. } r = 461.42 \text{ ft.} \\ M = 9^\circ\ 39'\ 46'',\ BE = 154.90 \text{ ft.} \end{cases}$

(14) Find the whole length of the cross-over in question 13, if a point switch is employed. Ans. $be = b'e' = 146.36$ ft.

(15) Solve question 14 if a straight-track cross-over is inserted instead of a reversed curve. Ans. $be = 147.93$ ft.

(16) If two straight tracks intersect at an angle of 68° 30′, find the dimensions of the crossing.

$$\text{Ans.}\begin{cases} F = 68° \ 30' \\ AB = BC = CE = EA = 5.06 \text{ ft.} \end{cases}$$

(17) A 6° 30′ curve crosses a straight track so that the angle of intersection of their center lines is 68°. Find the four frog angles of the crossing.

$$\text{Ans.}\begin{cases} F \ = 67° \ 53' \ 50'' \\ F_1 = 68° \ 13' \ 30'' \\ F_2 = 68° \ \ 6' \ 10'' \\ F_3 = 67° \ 46' \ 23'' \end{cases}$$

RAILROAD BUILDINGS AND MISCELLANEOUS STRUCTURES

EXAMINATION QUESTIONS

(1) What are the essential features of a passenger station, in the order of their importance?

(2) (*a*) Describe, in your own words, the main features of a section tool house. (*b*) Why should not the bottom of the structure be flush with the ground?

(3) Describe the distinguishing features of a roundhouse, and explain when and why a roundhouse is preferable to a rectangular engine house.

(4) At what distances should water stations usually be placed?

(5) Give a general description of a water station.

(6) Compute the capacity of the water tank illustrated in Fig. 7. Ans. 22,113 gal.

(7) Why should a turntable be somewhat longer than the longest engine that is to use it?

(8) How much labor and materials will be required to fence one side of a railroad 75 miles long?

(9) Under what conditions of topography is a snow shed necessary?

(10) (*a*) What is a ladder track and how is it used for the rapid distribution of cars to various tracks? (*b*) How

is the force of gravity used to facilitate the distribution of cars in a freight yard?

(11) (*a*) What is a cattle guard? (*b*) What is the form of cattle guard used by the best roads?

(12) What is the objection: (*a*) to open-pit cattle guards? (*b*) to surface cattle guards?

(13) What are the requirements of an ash-pit, so that it will be structurally durable?

HIGHWAYS

(PART 1)

EXAMINATION QUESTIONS

(1) (*a*) What conditions are essential to a road in order that it may be satisfactory for public travel? (*b*) What are the advantages of good roads? (*c*) On what does the cost of transportation by horses and wagons depend?

(2) (*a*) What forces oppose the motion of vehicles on roads? (*b*) Of these forces, which of them are independent of the condition of the road?

(3) (*a*) What effect has the width of the wheel tire on a road? (*b*) What should be the width of the tires on a four-wheel wagon intended to carry a load of 9,000 pounds? (*c*) What should be the width of the tires on a two-wheel cart carrying a load of $1\frac{1}{2}$ net tons?

Ans. $\begin{cases} (b)\ 7.5 \text{ in.} \\ (c)\ 5 \text{ in.} \end{cases}$

(4) A wheel 5.2 feet in diameter sustains a load of 1,200 pounds. What will be the tractive force required to draw the wheel over an obstacle .2 foot in height resting on a level roadway surface? Ans. 500 lb.

(5) What is the total tractive force necessary to haul a load of 10,000 pounds on a hard-rolled gravel roadway having a grade of 4 per cent.? Ans. 733 lb.

(6) What governs the load that a horse can draw on a road?

(7) (*a*) At what speed is the work done by a horse greatest? (*b*) The force exerted at this speed is what part

of the utmost tractive force that a horse can exert at a dead pull?

(8) What is the tractive force that can be exerted by an ordinary horse at a speed of 5 miles per hour?

Ans. 45.5 lb., nearly

(9) How are the different grades of a roadway classified?

(10) (*a*) Where should the easiest grades be used? (*b*) What limits the maximum grade?

(11) (*a*) What determines the suitable width for a road? (*b*) What parts of a road should be wider than others? (*c*) What is the common width of the right of way?

(12) (*a*) In determining the best route for a road, what conditions must be compared? (*b*) How should the grades be compared?

(13) What should be included in the comparison of the lengths of the routes?

(14) (*a*) When the route has been finally decided, how should the line be marked on the ground? (*b*) What should the engineering report of a proposed road contain?

(15) (*a*) What information should a construction profile show? (*b*) In establishing a grade, how is the earthwork equalized under different conditions?

HIGHWAYS

(PART 2)

EXAMINATION QUESTIONS

(1) (*a*) What effect has water on a road? (*b*) How is it removed?

(2) (*a*) What kinds of soils require subsoil drains? (*b*) Under what conditions is the drainage of rock strata necessary?

(3) What should be the minimum diameter of the tiles used for the subsoil drains of roadways?

(4) What are the important points to be attended to in the construction of drains?

(5) (*a*) What is a natural road? (*b*) What are the most common defects of ordinary country roads? (*c*) How can these defects be remedied?

(6) (*a*) What materials may be used in the construction of artificial roads? (*b*) What are the essential points to be observed in the construction of broken-stone roads? (*c*) What are the advantages and disadvantages of broken-stone roads?

(7) (*a*) What is to be considered in selecting a stone for a given road? (*b*) What methods are employed to ascertain the quality of a given stone?

(8) How are broken-stone roads classified?

(9) How are natural roads kept in good condition?

(10) (*a*) How are artificial roads kept in good condition? (*b*) What happens to broken-stone roads in dry weather? (*c*) What is done to prevent raveling?

(11) (*a*) How are shell roads constructed? (*b*) What is their chief advantage?

(12) Describe some other kinds of artificial roads, and state under what conditions each one should be used.

(13) On what does the thickness of the stone covering on a road depend?

(14) How should the earth foundation of a broken-stone roadway be prepared?

(15) Describe briefly the manner of applying the broken stone and finishing the surface of the roadway.

PAVEMENTS

EXAMINATION QUESTIONS

(1) What qualities are essential to a pavement?

(2) (*a*) How may the relative economic values of different pavements be compared? (*b*) What unit of length may be used in making the comparison? (*c*) How may the average cost per ton be obtained?

(3) What is the annual charge for first cost against a piece of granite-block pavement on a concrete foundation 1 yard in length on a roadway 10 yards wide? Ans. $2.432

(4) A roadway 36 feet in width is paved with asphalt on a concrete foundation. (*a*) What is the total annual expense chargeable against a piece of the pavement 1 yard long and the full width of the roadway? (*b*) During a continuous observation of 5 days, the number of vehicles passing over this pavement was found to be 3,835, classified as follows: 2,460 light; 1,115 medium; and 260 heavy. What was the average cost per ton-yard to the traffic?

Ans. { (*a*) $6.80
(*b*) .00207 ct.

(5) (*a*) Where is asphalt found? (*b*) What kinds of asphalt are found in Trinidad?

(6) (*a*) What is the specific gravity of asphalt, and what causes it to vary? (*b*) In what is asphalt soluble, and in what is it insoluble?

(7) (*a*) How is asphalt refined? (*b*) Is the refined product absolutely pure?

(8) (*a*) What should be the quality of the asphalt employed for paving? (*b*) How are the brittle asphalts prepared for use in paving? (*c*) How is the consistency of paving cement tested? (*d*) How are artificial asphalts produced?

(9) For what purpose is coal tar employed in paving?

(10) (*a*) What woods have been found to be the most suitable for pavements? (*b*) What varieties are used in the United States? (*c*) What properties should the wood used for paving possess?

(11) How should granite paving blocks be laid?

(12) (*a*) What is the most common defect of wooden pavements? (*b*) What forms the best foundation for brick pavements?

(13) Describe briefly how (*a*) the rectangular and (*b*) the cylindrical blocks should be laid in wood pavements. (*c*) By what method of joint filling are the best results obtained in rectangular wooden-block pavements? (*d*) In what manner should the spaces between the blocks of cylindrical wooden-block pavements be filled?

(14) (*a*) What will be the average expansion of ordinary pavements composed of untreated wooden blocks? (*b*) How long will it require for the wood to attain its full amount of expansion? (*c*) How should the expansion be provided for?

(15) What materials are employed for the foundations of asphalt pavements?

(16) (*a*) What is mixed with the asphalt paving cement to form the pavement? (*b*) What are the proportions of the ingredients in the paving mixture? (*c*) At what temperature are the ingredients mixed? (*d*) Describe briefly the method of mixing.

(17) (*a*) Of what does the rock asphalt commonly used for paving purposes in Europe consist? (*b*) Of what should the foundation for rock-asphalt pavement consist?

(18) (*a*) Of what do asphalt paving blocks commonly consist? (*b*) In what manner and in what sizes are the blocks formed? (*c*) For what streets are pavements formed of these blocks suitable?

(19) (*a*) What is a bitulithic pavement? (*b*) How is the foundation for a bitulithic pavement prepared?

CITY SURVEYING

EXAMINATION QUESTIONS

(1) What surveys are included in the surveying work to be done by a city engineer?

(2) What is the standard instrument for linear measurements in city work?

(3) The length of a line measured at a temperature of 50° is 488.76 feet. If the tape is standard at 62°, and the coefficient of expansion is taken as .0000065, what is the true length of the line? Ans. 488.722 ft.

(4) The length of a line measured with a tape .002 square inch in cross-section, under a pull of 15 pounds, is 906.56 feet. Assuming the coefficient of elasticity to be 28,000,000 pounds per square inch, determine the true length of the line.

Ans. 906.80 ft.

(5) What is the correction due to sag in a line 500 feet long, if the measurement is made with a 100-foot tape, weighing .008 pound per foot, under a pull of 20 pounds?

Ans. .033 ft.

(6) What pull is necessary to neutralize the sag in a 100-foot tape whose sectional area is .002 square inch, and weight .007 pound per foot? Assume the coefficient of elasticity to be 28,000,000 pounds per square inch.

Ans. 10.5 lb.

(7) The length of a line AB measured on a slope is 250 feet. If the elevation of A is 100 feet and that of B 104.48 feet, what is the horizontal distance between A and B?

Ans. 249.96 ft.

(8) What instrument is used for angular measurements in city work?

(9) Describe the process of measuring angles in city work.

(10) What is meant by the mean value of a measurement?

(11) A line measures 400.045 feet in winter when the temperature is $+10°$, and 399.871 feet in summer when the temperature is 80°. Determine the coefficient of expansion for the tape used, if that tape is standard at 62°.

Ans. .0000062

(12) A distance was measured four times, the results of the measurements being, respectively, 903.49, 903.47, 903.50, and 903.47 feet. Determine: (*a*) the mean value M of the distance; (*b*) the probable error p.

Ans. $\begin{cases} (a) \ 903.485 \text{ ft.} \\ (b) \ .005 \text{ ft.} \end{cases}$

(13) What is meant by the street line?

(14) What are the duties of a surveyor concerning encroachments?

(15) For what purpose are monuments in a city used?

(16) Assume a tract and lot, make a sketch, and describe the location of the lot both by the lot-and-block and by the metes-and-bounds method.

(17) Make a sketch of a city triangular block; assume dimensions, and show how to divide it into lots.

(18) Take a rectangular lot, assume the necessary dimensions and elevations, and determine the total excavation and fill, and the amount of material to be either removed or brought from outside, as the case may be, in order to bring the lot to a certain elevation.

CITY STREETS

EXAMINATION QUESTIONS

(1) (*a*) A common earth roadway 16 feet wide has a grade of 5 per cent.; how much crown should it have? (*b*) For an ordinary gravel roadway having the same width and grade, how much crown should there be? (*c*) If the gravel roadway is 20 feet wide and has a grade of 4 per cent., how much crown should it have?

Ans. (*a*) .475 ft.; (*b*) .360 ft.; (*c*) .440 ft.

(2) (*a*) A roadway 28 feet wide, having a grade of 3 per cent., is paved with wooden block pavement; how much crown should it have? If given a symmetrical curving crown, what will be the ordinates to the surface line of the cross-section at points distant from the center (*b*) 3.5 feet? (*c*) 7 feet?

Ans. (*a*) .400 ft.; (*b*) .025 ft.; (*c*) .1 ft.

(3) (*a*) A roadway 48 feet wide, having a grade of 1.6 per cent., is paved with a first-class asphalt pavement; how much crown should it have? (*b*) If given a symmetrical sloping crown with a central curve 6 feet in length, what will be the rate of the lateral slope for the uniformly sloping portion of the roadway surface? What will be the ordinates to the surface line of the cross-section at points distant from the center (*c*) 3 feet? (*d*) 6 feet? (*e*) 12 feet?

Ans. (*a*) .360 ft.; (*b*) .016 per ft.; (*c*) .024 ft.; (*d*) .072 ft.; (*e*) .168 ft.

(4) (*a*) A roadway 40 feet wide, having a grade of 2 per cent., is paved with a well-laid brick pavement; how much crown should it have? (*b*) If given a symmetrical sloping crown with a central curve 6 feet in length, what will be the rate of lateral slope for the uniformly sloping portion of the roadway surface?

Ans. $\begin{cases} (a) & .37 \text{ ft.} \\ (b) & .02 \text{ per ft} \end{cases}$

(5) On a certain street having a symmetrical cross-section, the entire space between each curb and the building line is occupied by a sidewalk 12 feet wide. At a cross-section where the street grade has an elevation of 124.62 feet, what should be the elevation of the sidewalk at the building line? Ans. 124.86 ft.

(6) Two streets that intersect at right angles have each a uniform grade of 3 per cent. throughout the intersection, and a roadway 40 feet in width. If both grade lines have the same elevation at the center of intersection, what will be the difference, as computed from the two grade lines, in the elevations of each of the four curb angles corresponding to the curb angles *a*, *b*, *c*, and *d* of Fig. 20?

Ans. $\begin{cases} \text{For } a, & 0 \text{ ft.} \\ \text{For } b, & 0 \text{ ft.} \\ \text{For } c, & 1.2 \text{ ft.} \\ \text{For } d, & 1.2 \text{ ft.} \end{cases}$

(7) (*a*) If the roadway of question 4 is given a lateral slope of 1 per cent. from curb to curb, what will be the difference in the elevations of the curbs? (*b*) What will be the eccentricity of crown necessary to give this difference in the elevations of the curbs? (*c*) With a difference of 1 foot between the elevations of the curbs, will the formula for eccentricity of crown apply? (*d*) With this difference in the elevation of the curbs, what will be the rate of uniform slope across the roadway?

Ans. $\begin{cases} (a) & .4 \text{ ft.} \\ (b) & 10 \text{ ft.} \\ (d) & .025 \text{ per ft.} \end{cases}$

(8) (*a*) For the roadway of question 3, what is the greatest difference between the elevations of the curbs to which the formula for eccentricity of crown will apply?

(*b*) What will be the eccentricity of crown necessary to give this difference between the elevations of the curbs? (*c*) What will be the eccentricity of crown necessary to give a difference of .6 foot between the elevations of the curbs? (*d*) What will be the per cent. of lateral slope from curb to curb, or, in other words, the per cent. of grade of the intersecting street giving this difference between the elevations of the curbs?

Ans. (*a*) .672 ft.
(*b*) 21.00 ft.
(*c*) 18.75 ft.
(*d*) 1.25 per cent.

(9) Name the different parts of a city street.

(10) What widths of roadways are used for different conditions of traffic?

(11) (*a*) What is curbing? (*b*) What materials are used for curbing?

(12) What materials are used for footways?

(13) What two conditions are desirable at the intersection of two streets?

(14) What are the main objects to be attained in fixing the grades of a system of streets?

(15) What is the general plan to be followed in fixing the grades of a system of streets?

(16) What information should be given in a record of street grades?

A KEY TO ALL THE QUESTIONS AND EXAMPLES

CONTAINED IN THE EXAMINATION QUESTIONS INCLUDED IN THIS VOLUME

The Keys that follow have been divided into sections corresponding to the Examination Questions to which they refer, and have been given corresponding section numbers. The answers and solutions have been numbered to correspond with the questions. When the answer to a question involves a repetition of statements given in the Instruction Paper, the reader has been referred to a numbered article, the reading of which will enable him to answer the question himself.

To be of the greatest benefit, the Keys should be used sparingly. They should be used much in the same manner as a pupil would go to a teacher for instruction with regard to answering some example he was unable to solve. If used in this manner, the Keys will be of great help and assistance to the student, and will be a source of encouragement to him in studying the various papers composing the course.

THE TRANSITION SPIRAL

(1) From Table I, in the column headed 50, we find opposite 3°, .427 ft. for a 3° curve; opposite 5°, .707 ft. for a 5° curve; and, .979 + $\frac{1}{2}$ (1.112 − .979) = 1.046 ft. for a 7° 30′ curve. Ans.

(2) No; from Table I, it is found that the superelevation of a 4° curve for this speed should be .811 ft.

(3) By formula **3**, Art. **12**, $a = 10° \div 3 = 3\frac{1}{3}°$. Therefore Table XIII should be used. This table gives:

$$\left.\begin{array}{lll} \text{At first stake,} & d = 2° 20' + \frac{1}{2} \times (2° 40' - 2° 20') = & 2° 30' \\ \text{At second stake,} & d = & 5°\ 0' \\ \text{At third stake,} & d = 7° 20' + \frac{1}{2} \times (7° 40' - 7° 20') = & 7° 30' \\ \text{At P. S}_2\text{,} & d = & 10°\ 0' \end{array}\right\} \text{Ans.}$$

Solution by formula **1**, Art. **12**:

$$\left.\begin{array}{ll} \text{At first stake,} & d = 3\frac{1}{3}° \times .75 = 2° 30' \\ \text{At second stake,} & d = 3\frac{1}{3}° \times 1.50 = 5°\ 0' \\ \text{At third stake,} & d = 3\frac{1}{3}° \times 2.25 = 7° 30' \\ \text{At P. S}_2\text{,} & d = 3\frac{1}{3}° \times 3.00 = 10°\ 0' \end{array}\right\} \text{Ans.}$$

(4) Solution by Table I:

$$\left.\begin{array}{l} \text{At first stake,} \\ d = 2° 30'\text{; superelevation} = .183 + \frac{1}{2} \times (.274 - .183) = .229 \text{ ft.} \\ \text{At second stake,} \quad d = 5°\text{; superelevation} = .455 \\ \text{At third stake,} \\ d = 7° 30'\text{; superelevation} = .634 + \frac{1}{2} \times (.723 - .634) = .679 \\ \text{At P. S}_2\text{,} \quad d = 10°\text{; superelevation} = .898 \end{array}\right\} \text{Ans.}$$

Solution by the formula of Art. **13**: Superelevation at P. S_2, from Table I, = .898 ft. Hence,

$$\left.\begin{array}{ll} \text{At first stake,} & e = \frac{.75}{3} \times .898 = .225 \text{ ft.} \\ \text{At second stake,} & e = \frac{1.5}{3} \times .898 = .449 \text{ ft.} \\ \text{At third stake,} & e = \frac{2.25}{3} \times .898 = .674 \text{ ft.} \end{array}\right\} \text{Ans.}$$

(5) By formula **3**, Art. **12**, $a = \frac{4}{5}°$; therefore, Table V should be used. Opposite the lengths 100, 200, etc. in the first column, the following values of δ and θ are found:

$$\left.\begin{array}{ll} \text{At first stake,} & \delta = 0°\,24',\ \theta = 0°\ \ 8' \\ \text{At second stake,} & \delta = 1°\,36',\ \theta = 0°\,32' \\ \text{At third stake,} & \delta = 3°\,36',\ \theta = 1°\,12' \\ \text{At fourth stake,} & \delta = 6°\,24',\ \theta = 2°\ \ 8' \\ \text{At P. S}_2\text{,} & \delta = 10°\ \ 0',\ \theta = 3°\,20' \end{array}\right\}\text{Ans.}$$

(6) The formula of Art. **19** is to be used. From Table V,

$$\text{Deviation angle} = 4°\,54' + \tfrac{10}{25} \times (5°\,37\tfrac{1}{2}' - 4°\,54') = 5°\,11.4'$$
$$\text{Deflection angle} = 1°\,38' + \tfrac{10}{25} \times (1°\,52\tfrac{1}{2}' - 1°\,38') = 1°\,43.8'$$
$$\text{Desired angle} = 3°\,27.6' \quad \text{Ans.}$$

(7) (*a*) From formula **3**, Art. **12**, $a = 3° \div 6 = \frac{1}{2}°$. From Table II,

$$x \text{ cor.} = .75 + \tfrac{15}{25} \times (.95 - .75) = .87 \text{ ft.}$$

$CP = 540$ ft. Therefore, by Art. **20**,

$$CR = 540 - .87 = 539.13 \text{ ft.} \quad \text{Ans.}$$

(*b*) From Table II,

$$y = PR = 21.03 + \tfrac{15}{25} \times (24.17 - 21.03) = 22.91 \text{ ft.} \quad \text{Ans.}$$

(8) (*a*) From Table II, opposite the length 500, t cor. = .10. Therefore (Art. **21**),

$$CV = \tfrac{1}{2} \times 500 - .10 = 249.90 \text{ ft.} \quad \text{Ans.}$$

(*b*) From Table II,

$$F = \text{spiral offset} = VE = 4.54. \quad \text{Ans.}$$

(*c*) From Table II, opposite 250,

$$y = LM' = 2.27. \quad \text{Ans.}$$

(9) The formula of Art. **23** is to be applied. By formula **3**, Art. **12**, $a = 4° \div 2 = 2°$. Therefore, Table XI should be used.

From the formula $R = \dfrac{5{,}730}{D}$,

$$R = 5{,}730 \div 4 = 1{,}432.50 \text{ ft.}$$

From Table XI, opposite 200, $F = \quad 1.16$

$$R + F = 1{,}433.66 \text{ ft.}$$
$$(R + F) \tan \tfrac{1}{2} I = 1{,}433.7 \tan 54° = 1{,}973.3$$
$$\tfrac{1}{2} \text{ length of spiral} = \tfrac{1}{2} \times 200 = \quad 100.0$$
$$t \text{ cor., from Table XI,} \quad = \quad 0.0$$

Therefore, by the formula of Art. **23**, $CT = 2{,}073.3$ ft. Ans.

(10) (*a*) From Table XI, deviation angle to P. S_2 = AVT, Fig. **11**, $= AOV = BOV' = 4°$ = central angle of spiral. Ans.

(*b*) Central angle of circular curve is

$$AOB = 108° - 2 \times 4° = 100°. \quad \text{Ans.}$$

(11) Since TC, by question 9, is 2,073.3 ft., the station number of the P. S_1, will be

$$\left.\begin{array}{ll} (401+88.3)-(20+73.3) \ldots\ldots\ldots\ldots & = 381+15 \\ \text{Station number of } A \text{ is } (381+15)+(2+00) \ldots & = 383+15 \\ \text{From question 10, the length } AB = 100^\circ \div 4^\circ = 25 \text{ sta.} & \\ \text{Station number of } B \text{ is P. } S_2' = (383+15)+(25+00) & = 408+15 \\ \text{Station number of } C' \text{ is P. } S_1' = (408+15)+(2+00) & = 410+15 \end{array}\right\}\text{Ans.}$$

(12) From question 9, unit degree of curve of spiral = 2°; spiral offset = 1.16 ft.; $CV = C'V'$, Fig. 11, = 100.0 ft.; $CT = C'T$ = 2,073.3 ft.

The transit at P. S_1.—From Table XI, the following deflection angles are taken:

$$\left.\begin{array}{ll} \text{to first stake,} & 0^\circ\ 5' \\ \text{to second stake,} & 0^\circ\ 20' \\ \text{to third stake,} & 0^\circ\ 45' \\ \text{to P. } S_2 = 383+15.0 = \text{fourth stake,} & 1^\circ\ 20' \end{array}\right\}(A)$$

The transit at P. S_2.—The angle NPC, Fig. 7, $= \Delta - \theta = 4^\circ - 1^\circ 20'$ $= 2^\circ 40'$. The deflection angles to locate stakes on the circular curve are:

$$\left.\begin{array}{ll} \text{to Sta. 384, } \frac{1}{2}\times 4^\circ \times .85 & = 1^\circ\ 42' \\ \text{to Sta. 385, } 2^\circ + 0^\circ\ 51' & = 3^\circ\ 42' \\ \text{to Sta. 386, } 2^\circ\ 51' + 2^\circ & = 5^\circ\ 42' \end{array}\right\}(B)$$

The curve is too long to be located entirely from the point A. It will, however, be run in from A to B exactly as any simple circular curve.

The field work.—Run the two tangents to their intersection. Measure back from T the equal distances $TC = TC' = 2{,}073.3$ ft., and set stakes marked P. S_1 at C and C'. Set the transit at C with the vernier at 0° 0′, sight on T, and deflect the angles (A) above to locate the first spiral. When the stake at A (marked P. S_2) has been set, move to A, set the vernier at 2° 40′, backsight on C, turn the telescope until the vernier reads 0° 0′, and from this direction deflect the angles (B) to locate the circular curve. When the stake at B (marked P. S_2) has been set, move to C', set the vernier at 0° 0′, backsight on T, and deflect the angles (A) to locate the second spiral.

(13) From a table of radii and deflections, the radius of a 4° curve is found to be 1,432.7. From question 9, the spiral offset is 1.16. Substituting these values in formula **2**, Art. **34**,

$$q_1 = (1{,}432.7 + 1.16) \sec 54^\circ - 1{,}432.7 = 1{,}006.8 \text{ ft.} \quad \text{Ans.}$$

(14) The throw VM, Fig. 8, of track will always be very nearly equal to one-half of the spiral offset, as shown in Art. **22**. The spiral offset will therefore be $2 \times 2.8 = 5.6$ ft., nearly. Substituting $F = 5.6$ and $D = 6$ in formula **2**, Art. **35**, we have,

$$L = 3.7086 \times \sqrt{\frac{5.6}{6}} = 3.583 \text{ sta.} \quad \text{Ans.}$$

A length of 360 ft. would doubtless be chosen; a would then be $6° \div 3.6 = 1° 40'$, and Table X could be used.

(15) Since VM, Fig. 15, may be 2 ft., the spiral offset $VE = F$ may be 4 ft. The external to the given unspiraled curve is found by formula **1**, Art. **33**, to be 113.69 ft. Substituting the values in the formula of Art. **40**,

$$q' = 113.69 - 4 \sec 30° 20' - \tfrac{4}{2} = 107.06 \text{ ft.}$$

The radius of the new curve may be found from formula **1**, Art. **33**, which gives

$$R = \frac{q' \cos \frac{1}{2} I}{2 \sin^2 \frac{1}{4} I} = \frac{107.06 \cos 30° 20'}{2 \sin^2 15° 10'} = 675 \text{ ft.}$$

The degree of curve corresponding to this radius is 8° 30′, nearly. Ans.

The length of spiral will be (formula **2**, Art. **35**),

$$L = 3.7086\sqrt{\frac{4}{8.5}} = 2.54 \text{ sta.} = 254 \text{ ft.} \quad \text{Ans.}$$

The practical selection would probably be $D = 8° 30'$ and $L = 250$. The spiral offset would be,

$$F = .072709 \times \frac{8.5}{2.5} \times (2.5)^2 = 3.86$$

This would produce a throw of $3.86 \div 2 = 1.93$ ft.

(16) From question 15, the external to the old curve is 113.69. Substituting in formula **1**, Art. **38**,

$$q' = 113.69 - 4 \sec 30° 20' = 109.06 \text{ ft.}$$

Substituting this value in the formula given in question 15,

$$R = \frac{109.06 \cos 30° 20'}{2 \sin^2 15° 10'} = 687.6$$

The degree of curve corresponding to this radius is 8° 20′. The length of spiral is

$$L = 3.7086 \times \sqrt{\frac{4}{8.333}} = 2.57 \text{ sta.} = 257 \text{ ft.} \quad \text{Ans.}$$

A length of 250 ft. would doubtless be chosen.

(17) (a) Substituting known values in the last equation of Art. **36**,

$$a = \tfrac{1}{2} \times \left(\tfrac{60}{50}\right)^3 = \left(\tfrac{108}{125}\right)°$$

Substituting this value in formula **3**, Art. **12**,

$$L = 5 \div \tfrac{108}{125} = 5.787 \text{ sta.} = 578.7 \text{ ft.} = \text{best length.} \quad \text{Ans.}$$

(b) From the table in Art. **37**, we find the value of a corresponding to 50 mi. per hr. to be 1°. Therefore,

$$L = 5 \div 1 = 5 \text{ sta.} = 500 \text{ ft.} = \text{least length.} \quad \text{Ans.}$$

EARTHWORK

(1) The elevations of the subgrade at the various stations are as follows (see Art. 15):

Station	Elevation, in Feet
21	164.60
22	164.60 − 1 × 1.3 = 163.30
23	164.60 − 2 × 1.3 = 162.00
24	164.60 − 3 × 1.3 = 160.70
24 + 40	160.70 + .4 × .6 = 160.94
25	160.70 + 1 × .6 = 161.30
26	160.70 + 2 × .6 = 161.90
27	160.70 + 3 × .6 = 162.50

The differences between these elevations and the elevations of the natural surface give the cuts or fills at the various stations:

Station	Cuts and Fills
21	164.60 − 162.3 = F 2.3
22	163.30 − 160.4 = F 2.9
23	162.00 − 158.7 = F 3.3
24	160.70 − 160.0 = F .7
24 + 40	160.94 − 157.9 = F 3.0
25	162.4 − 161.30 = C 1.1
26	162.70 − 161.90 = C .8
27	164.50 − 162.50 = C 2.0

(2) The elevation of the subgrade at each station is given in the first of the following columns, the elevation of the natural surface in the second, and the cut or fill in the third:

Station	Elevation of Subgrade	Elevation of Natural Surface	Cuts and Fills
21	157.14	162.3	C 5.2
22	157.14 + 1 × 1.1 = 158.24	160.4	C 2.2
23	157.14 + 2 × 1.1 = 159.34	158.7	F .6
24	157.14 + 3 × 1.1 = 160.44	160.0	F .4
24 + 40	157.14 + 3.4 × 1.1 = 160.88	157.9	F 3.0
25	160.88 + 0.6 × 1.6 = 161.84	162.4	C .6
26	160.88 + 1.6 × 1.6 = 163.44	162.7	F .7
27	160.88 + 2.6 × 1.6 = 165.04	164.5	F .5

(3) To apply formula **1**, Art. **17**, we have $\frac{1}{2}b = 11$ ft., $s = 2$, $d = 4.1$, and $y = 5.3 - 1.3 = 4$; therefore, the computed distance is

$$11 + 2 \times 4.1 + 2 \times 4.0 = 27.2 \text{ ft.}$$

As the measured distance 28 ft. is greater than this, the trial point must be moved in slightly.

(4) To apply formula **2**, Art. **17**, we have $\frac{1}{2}b = 11$ ft., $s = 2$, $d = 4.1$, and $y' = 7.8 - 5.3 = 2.5$ ft.; therefore, the computed distance is

$$11 + 2 \times 4.1 - 2 \times 2.5 = 14.2 \text{ ft.}$$

As the measured distance 13.5 ft. is smaller than this, the trial point must be moved out slightly.

(5) The area of the first triangle is

$$\tfrac{1}{2} \times 20 \times 10 = 100 \text{ sq. ft.}$$

The area of the second triangle is

$$\tfrac{1}{2} \times 5 \times 7 = 17.5 \text{ sq. ft.}$$

By formula **2**, Art. **21**,

$$V_1 = \frac{100}{2 \times 27} \times (100 + 17.5) = 218 \text{ cu. yd.}$$

Substituting the given values in formula **1**, Art. **23**,

$$C = \frac{100}{12 \times 27} \times (20 - 5) \times (7 - 10) = -14 \text{ cu. yd.}$$

Then, $V = V_1 + C = 218 - 14 = 204$ cu. yd. Ans.

(6) The computation will be arranged as in the following table:

Sta.	$a + d$	w	Volumes	
			(a)	(b)
21 + 30	14.8	47.1	645	250
21	13.0	45.3	545	440
20	9.0	30.1	251	

Ans. $V_1 = 690$

Since the slope is $1\frac{1}{2} : 1$ and the width of roadbed is 24 ft.,

$$a = \frac{\frac{1}{2} \times 24}{\frac{3}{2}} = 8 \text{ ft. for all sections}$$

The sum of the center depth at each station and the number a is written in the second column, and the total width, which is the sum of the two denominators of the slope-stake fractions at each station, is written in the third column. The value of $\frac{100}{4 \times 27}(a + d)\,w$ is written in column 4 (a).

Thus, at Sta. 20, $d = 1.0$, $a+d = 8.0+1.0 = 9.0$, $w = 18.0+12.1 = 30.1$, and

$$\frac{100}{4 \times 27}(a+d)\,w = \frac{100}{4 \times 27} \times 9.0 \times 30.1 = 251 \text{ cu. yd.}$$

Similarly for the others.

The value of $\frac{2 \times 100}{4 \times 27} \times a\,b$ is $\frac{2 \times 100}{4 \times 27} \times 8.0 \times 24.0 = 356$ cu. yd.

Therefore, by formula **1**, Art. **25**,

Volume between Sta. 20 and Sta. 21 is $251 + 545 - 356$ . . . . $= 440$ cu. yd.

Volume between Sta. 21 and Sta. $21 + 30$ is $\frac{3}{10}(545 + 645 - 355)$ . . . . $= 250$ cu. yd.

Total volume . . . . $= 690$ cu. yd. Ans.

(7) In accordance with the directions for applying formula in Art. **26**, we have the following series at Sta. $24 + 35$:

$$\frac{0}{11.0} \quad \frac{5.9}{19.9} \quad \frac{8.1}{0} \quad \frac{11.4}{28.1} \quad \frac{0}{11.0}$$

The plus areas, therefore, are

$$\begin{aligned} 11.0 \times 5.9 &= 64.9 \\ 19.9 \times 8.1 &= 161.2 \\ 8.1 \times 28.1 &= 227.6 \\ 11.4 \times 11.0 &= 125.4 \\ \text{Sum} &= 579.1 \end{aligned}$$

The minus areas are all zero.

At Sta. 25, we have the series,

$$\frac{0}{11.0} \diagup \frac{0.6}{11.9} \diagup \frac{2.4}{0} \diagdown \frac{4.7}{18.0} \diagdown \frac{0}{11.0}$$

from which the plus areas are,

$$\begin{aligned} 11.0 \times .6 &= 6.6 \\ 11.9 \times 2.4 &= 28.6 \\ 2.4 \times 18.0 &= 43.2 \\ 4.7 \times 11.0 &= 51.7 \\ \text{Sum} &= 130.1 \end{aligned}$$

Each of the minus areas is zero.

We have, therefore, $A_1 = \frac{1}{2} \times 579.1$

$A_2 = \frac{1}{2} \times 130.1$

For applying the equation in Art. **28**, we have

$$\frac{100}{2 \times 27} A_1 = \frac{100}{4 \times 27} \times 579.1 = 536 \text{ cu. yd.}$$

Therefore, $$\frac{100}{2 \times 27} A_2 = \frac{100}{4 \times 27} \times 130.1 = 120 \text{ cu. yd.}$$

$$V_1 = \frac{65}{100} \times (536 + 120) = 426 \text{ cu. yd.} \quad \text{Ans.}$$

The arrangement of the computation is as follows:

Sta.	Plus Areas	Minus Areas	Cubic Yards	
			(a)	(b)
25	6.6 28.6 43.2 51.7		120	426
24 + 35	64.9 161.2 227.6 125.4		536	

(8) The computation will be tabulated as follows:

Sta.	$w - w'$	$d' - d$	Prismoidal Correction
21 + 30	− 1.8	+ 1.8	0
21	− 15.2	+ 4.0	− 19
20			

Total prismoidal correction = − 19 cu. yd.

Formula **2**, Art. **25**, is applied. The values of $w - w'$ are obtained by subtracting each value of w in the table in the solution of question 6 from the value just below it in the table; the values of $d' - d$ are obtained by subtracting each center depth from the value just above it in the notes of example 6. Thus, we have:

At Sta. 21,

$$w - w' = 30.1 - 45.3 = -15.2;\ d' - d = 5.0 - 1.0 = +4.0$$

At Sta. 21 + 30,

$$w - w' = 45.3 - 47.1 = -1.8;\ d' - d = 6.8 - 5.0 = +1.8$$

Substituting these values in formula **2**, Art. **24**, we have for the prismoid:

Between Sta. 20 and Sta. 21,

$$C = \frac{100}{12 \times 27} \times (-15.2) \times 4 = -19 \text{ cu. yd.}$$

Between Sta. 21 and Sta. 21 + 30,

$$C = \frac{30}{12 \times 27} \times (-1.8) \times 1.8 = -\underline{0} \text{ cu. yd.}$$

Total prismoidal correction = − 19 cu. yd.

Since from question 6, V_1 = 690 cu. yd., we have

$$V = V_1 + C = 690 - 19 = 671 \text{ cu. yd.} \quad \text{Ans.}$$

(9) The cross-section of the cut at Sta. 100 is shown in Fig. 1. The area of the section $p\,q\,t\,v$ is equal to the area of the triangle $p\,r\,t$

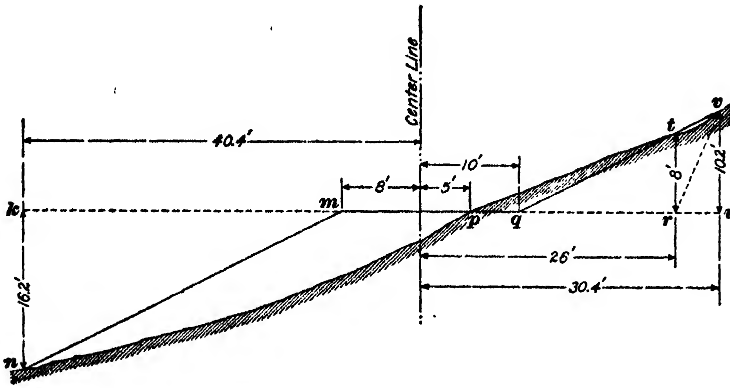


FIG. 1

plus the area of the triangle $r\,t\,v$ minus the area of the triangle $q\,r\,v$. $p\,r = 26 - 5 = 21$ ft., $q\,r = 26 - 10 = 16$ ft., $r\,u = 30.4 - 26 = 4.4$ ft.;

$$A_1 = \tfrac{1}{2} \times (21 \times 8 + 8 \times 4.4 - 16 \times 10.2) = 20 \text{ sq. ft.}$$

Similarly, the area of the cut at Sta. 101 is

$$A_2 = \tfrac{1}{2} \times (53.5 \times 20.1 - 40.2 \times 20.1) = 133.7 \text{ sq. ft.}$$

Substituting these values in formula **2**, Art. **21**,

$$V_1 = \frac{100}{2 \times 27} \times (20 + 133.7) = 285 \text{ cu. yd.}$$

Substituting known values in formula **1**, Art. **23**,

$$C = \frac{100}{12 \times 27} \times (5.0 - 13.3) \times (20.1 - 10.2) = -25 \text{ cu. yd.}$$

$$V = 285 - 25 = 260 \text{ cu. yd.} \quad \text{Ans.}$$

(10) The area of the fill at Sta. 100 (see Fig. 1) is $\frac{1}{2} \times (13 \times 16.2) = 105.3$ sq. ft. The area of the fill at Sta. 101 is $\frac{1}{2} \times [(8 - 3.3) \times 10] = 23.5$ sq. ft. Therefore,

$$V_1 = \frac{100}{2 \times 27} \times (105.3 + 23.5) = 239 \text{ cu. yd.}$$

The prismoidal correction is

$$C = \frac{100}{12 \times 27} \times (13 - 4.7) \times (10 - 16.2) = -16 \text{ cu. yd.}$$

Therefore, $V = 239 - 16 = 223$ cu. yd. Ans.

(11) To apply formula **2**, Art. **38**, we have the following values of $x_l - x_r$ from the notes:

At Sta. 21 + 30,	29.1 − 18.0 = 11.1
At Sta. 21,	28.2 − 17.1 = 11.1
At Sta. 20,	18.0 − 12.1 = 5.9

From the solution of question 6, we have the following values of $\frac{100}{2 \times 27} A + \frac{100}{2 \times 27} T$: at Sta. 21 + 30, 645; at Sta. 21, 545; at Sta. 20, 251.

Substituting these values, and also the value $R = 478$ in formula **2**, Art. **38**, we have the following values for the correction for curvature:

Between Sta. 21 + 30 and Sta. 21,

$$C_c = \frac{30}{100} \times \frac{1}{3 \times 478} \times (645 \times 11.1 + 545 \times 11.1) = 3 \text{ cu. yd.}$$

Between Sta. 21 and Sta. 20,

$$C_c = \frac{1}{3 \times 478} \times (545 \times 11.1 + 251 \times 5.9) = 5 \text{ cu. yd.}$$

The total correction is, therefore,

$$3 + 5 = 8 \text{ cu. yd.} \quad \text{Ans.}$$

Since, at each station, x_l is greater than x_r, the center of gravity lies to the left of the center line; and since the curve turns to the left, this point is inside of the curve. The volume V is, therefore, less than the uncorrected volume, and C_c is to be subtracted.

(12) Since the center stake at Sta. 100 is in the fill, formulas **3** and **4**, Art. **41**, must be applied. See Fig. 1. Here, $x_f = 40.4$, $\frac{1}{2} b = 8$, $n c = 5$, and $y_f = 16.2$.

Therefore, $e_1 = \frac{1}{3} \times (40.4 + 8 - 5) = 14.5$ ft.

and $A_1 = \frac{1}{2} \times (8 + 5) 16.2 = 105.3$ sq. ft.

Since the center stake at Sta. 101 is in the cut, formulas **1** and **2**, Art. **41**, must be applied: Here, $x_f = 28$, $\frac{1}{2} b = 8$, $n c = 3.3$, and $y_f = 10$.

Therefore, $e_2 = \frac{1}{3} \times (28 + 8 + 3.3) = 13.1$ ft.

and $A_2 = \frac{1}{2} \times (8 - 3.3) 10 = 23.5$ sq. ft.

Substituting these values and also $R = 716$ in the formula of Art. **36**,

$$C_c = \frac{100}{2 \times 27 \times 716} \times (14.5 \times 105.3 + 13.1 \times 23.5) = 5 \text{ cu. yd.} \quad \text{Ans.}$$

Since the center of gravity is on the left of the center line, and the curve turns to the left, this point is inside of the curve, and the correction for curvature is to be subtracted.

(13) From Art. **42**, it is seen that the shrinkage for sand is 8 per cent. Therefore, the amount of embankment that can be made from 671 cu. yd. of excavation (see question 8) is

$$671 - 671 \times .08 = 617 \text{ cu. yd.} \quad \text{Ans.}$$

RAILROAD LOCATION

(1) See Art. **3.**

(2) See Art. **9.**

(3) See Art. **4.**

(4) (*a*) See Art. **15.**
(*b*) See Art. **16.**

(5) (*a*) See Art. **22.**
(*b*) Read Arts. **23** to **28.**

(6) Read Arts. **29** to **33.**

(7) See Art. **34.**

(8) See Art. **53.**

(9) Read Art. **64.**

(10) See Art. **81.**

(11) See Art. **71.**

(12) Read Arts. **73** to **75.**

(13) See Art. **78.**

(14) See Art. **79.**

(15) The maximum gradient is

$$1.00 - (.04 \times 7) = .72 \text{ per cent. Ans.}$$

(16) The maximum gradient on the curve is

$$2.00 - (.04 \times 8) = 1.68 \text{ per cent. Ans.}$$

(17) By constructing a figure for each case, it is seen that (*a*), (*d*), and (*f*) are sags; (*b*), (*c*), and (*e*) are spurs. Ans.

(18) The case is evidently that of a spur, as in Fig. 27. The uncorrected elevations are:

Of C, 331.01 = E
Of second stake, 331.61
Of third stake, 332.21
Of fourth stake, 332.81
Of V, 333.41 = H
Of sixth stake, 333.21
Of seventh stake, 333.01
Of eighth stake, 332.81
Of D, 332.61 = E'

Therefore, $\frac{E + E'}{2} = \frac{1}{2}(331.01 + 332.61) = 331.81$, and from formula **1**, Art. **98**,

$$VM = \frac{1}{2}(333.41 - 331.81) = .80 \text{ ft.}$$

The corrections at each stake are now found by formula **2**, Art. **98**.

At second and eighth, $\left(\frac{50}{200}\right)^2 \times VM = \frac{1}{16} \times .80 = .05$ ft.

At third and seventh, $\left(\frac{100}{200}\right)^2 \times VM = \frac{1}{4} \times .80 = .20$ ft.

At fourth and sixth, $\left(\frac{150}{200}\right)^2 \times VM = \frac{9}{16} \times .80 = .45$ ft.

The corrected elevations are:

$$\left.\begin{array}{l} C,\ 331.01 - 0.00 = 331.01 \\ 2,\ 331.61 - 0.05 = 331.55 \\ 3,\ 332.21 - 0.20 = 332.01 \\ 4,\ 332.81 - 0.45 = 332.36 \\ V,\ 333.41 - 0.80 = 332.61 \end{array}\right\}\text{Ans.} \qquad \left.\begin{array}{l} 6,\ 333.21 - 0.45 = 332.76 \\ 7,\ 333.01 - 0.20 = 332.81 \\ 8,\ 332.81 - 0.05 = 332.76 \\ D,\ 332.61 - 0.00 = 332.61 \end{array}\right\}\text{Ans.}$$

(19) By Art. **100**, $G = 1.6 - 0.6 = 1$. By Table II, it is seen that a 400-ft. curve may be used.

Uncorrected elevations . . .	53.80	53.00	52.20	51.40	50.60	50.30	50.00	49.70	49.40	
Corrections, from Table II, for $G = 1.0$	.00	.03	.13	.28	.50	.28	.13	.03	.00	
Corrected elevations	53.80	53.03	52.33	51.68	51.10	50.58	50.13	49.73	49.40	Ans.

The corrections are added, since there is evidently a sag.

TRESTLES

(1) See Arts. **2, 3,** and **4.**

(2) From Table I, it is seen that, at 20 ct. per cu. yd., the cost of an embankment 20 ft. high is $652 per section of 100 ft. At $35 per M., B. M., the cost of a framed trestle of the same height is $631, per section of 100 ft. Therefore, the embankment is the more expensive.

(3) The maximum economical height for a pile trestle is 30 feet. See Art. **6.**

(4) See Arts. **10, 11,** and **12.**

(5) See Arts. **27** and **33.**

(6) (*a*) See Art. **27.**
(*b*) See Art. **28.**
(*c*) See Art. **29.**

(7) See Art. **30.**

(8) See Art. **31.**

(9) (*a*) See Art. **5.**
(*b*) and (*c*) See Art. **34.**

(10) See Arts. **35, 36,** and **37.**

(11) Read Art. **38.**

(12) See Art. **41.**

(13) (*a*) See Art. **43.**
(*b*) See Arts. **30** and **31.**

(14) See Art. **48.**

(15) See Art. **50.**

(16) See Art. **58.**

(17) See Art. **83.**

(18) See Art. **66.**

TRACKWORK
(PART 1)

(1) (*a*) See Art. **3.**
(*b*) See Art. **44.**

(2) (*a*) See Art. **9.**
(*b*) See Art. **12.**
(*c*) See Arts. **12** and **28.**

(3) By Table II, the number of oak ties is 2,348, and the number of tamarack ties is 2,640.

First cost of oak ties,

$$.80 \times 2{,}348 = \$1{,}878.40$$

Total cost of oak ties,

$$1.10 \times 1878.40 = \qquad \$2{,}066.24$$

Cost of each tamarack tie,

$$.22 + .25 + .18 = \$.65$$

Total cost of tamarack ties,

$$2{,}640 \times .65 = \qquad \underline{1{,}716.00}$$

The tamarack ties are therefore cheaper by $\quad$ \$ 350.24 $\quad$ Ans.

(4) By the rule of Art. **20,** the weight per yard is

$$\frac{120{,}000}{8 \times 224} = 67 \text{ lb.} \quad \text{Ans.}$$

By the rule of Art. **21,** the weight per yard is

$$120{,}000 \div 2{,}000 = 60 \text{ lb.} \quad \text{Ans.}$$

(5) See Art. **33.**

(6) From Table III, the weight of rail per mile is 78.57 T. The total cost is

$$1.02 \times 78.57 \times 30 = \$2{,}404.24. \quad \text{Ans.}$$

(7) From Table IV, 377 pairs are required. The cost is

$$377 \times 1.6 = \$603.20. \quad \text{Ans.}$$

(8) From Table IV, the number of bolts is 2,262. From Table V, the number of bolts to a keg is 305. Therefore, the number of kegs required is

$$2{,}262 \div 305 = 7.416$$

The price per keg at 2.4 cents a pound is

$$.024 \times 200 = \$4.80$$

Therefore, the total cost is

$$7.416 \times 4.8 = \$35.60. \quad \text{Ans.}$$

(9) From Table VI, the number of pounds required is 5,170. Therefore, the cost is

$$5{,}170 \times .016 = \$82.72. \quad \text{Ans.}$$

(10) (*a*) From Table VII, the space for a 30-ft. rail is $\frac{3}{16}$ in. Ans.

(*b*) From the principle explained in Art. **55**, the space for a 40-ft. rail is

$$\frac{40}{30} \times \frac{3}{16} = \frac{1}{4} \text{ in.} \quad \text{Ans.}$$

(11) By rule I, Art. **57**, the difference is

$$5 \times 9.6 \times 1\tfrac{1}{32} = 49.50 \text{ in.} = 4.125 \text{ ft.} \quad \text{Ans.}$$

(12) (*a*) By formula **1**, Art. **58**, since the radius of a 4° curve = 1,432.69 ft., the middle ordinate is

$$\frac{30^2}{8 \times 1{,}432.69} = .0785 \text{ ft.} = .942 \text{ in.} = \frac{15}{16} \text{ in., nearly.} \quad \text{Ans.}$$

(*b*) By formula **2**, Art. **58**, the quarter ordinates are

$$\frac{3}{4} \times .942 = .707 \text{ in.} = \frac{45}{64} \text{ in., nearly.} \quad \text{Ans.}$$

(13) From Art. **60**, the increase in gauge is

$$8 \times \frac{1}{16} = \frac{1}{2} \text{ in.} \quad \text{Ans.}$$

(14) From Art. **60**, the increase in gauge is

$$4 \times \frac{1}{16} = \frac{1}{4} \text{ in.}$$

From Art. **62**, the space is

$$1\tfrac{7}{8} \text{ in.} + \frac{1}{4} \text{ in.} = 2\tfrac{1}{8} \text{ in.} \quad \text{Ans.}$$

(15) From Art. **65**, the amount is

$$\frac{300}{2} \times 15 \times \frac{9}{10} \times \frac{1}{27} = 75 \text{ cu. yd.} \quad \text{Ans.}$$

TRACKWORK

(PART 2)

(1) From formula **2**, Art. **18**,

$$\cot \tfrac{1}{2} F = 2 \times 5 = 10;$$

whence $\tfrac{1}{2} F = 5° 42' 38''$, and $F = 11° 25' 16''$. Ans.

(2) The frog angle is 14° 15′. Therefore, from formula **1**, Art. **18**,

$$n = \tfrac{1}{2} \cot \tfrac{1}{2}(14° 15') = 4. \quad \text{Ans.}$$

(3) Here $s h$ = 8 ft. = 96 in., $a b$ = 16 in., and $d e$ = 8 in. Substituting these values in the formula of Art. **19**,

$$n = \frac{96}{16 + 8} = 4. \quad \text{Ans.}$$

(4) To apply formula **4**, Art. **21**, we have g = 4.708, and n = 11.5. Substituting these values,

$$r = 2 \times 4.708 \times (11.5)^2 = 1{,}245.3 \text{ ft.} \quad \text{Ans.}$$

(5) To apply formula **2**, Art. **21**, we have g = 4.708, and n = 11.5. Substituting these values,

$$L = 2 \times 4.708 \times 11.5 = 108.28 \text{ ft.} \quad \text{Ans.}$$

(6) (*a*) To apply formula **2**, Art. **22**, we have $t = 5\tfrac{1}{2}$ in. $= \tfrac{11}{24}$ ft., and r = 680.36 ft. Substituting these values,

$$l = \sqrt{2 \times 680.36 \times \tfrac{11}{24}} = 24.97 \text{ ft.} \quad \text{Ans.}$$

(*b*) From Table II, l = 24.93 ft. Ans.

(7) From the third column of Table II, L is found to be 84.75 ft.; from the fifth column, r = 762.75 ft.; from the seventh column, l = 26.43 ft.; and from the eighth column, $K a$ = 3.37 ft. Hence,

$$A K = 84.75 - 26.43 = 58.32 \text{ ft.}$$

and the length of straight main-track rail $A a$ is

$$58.32 - 3.37 = 54.95 \text{ ft.} \quad \text{Ans.}$$

(8) From the third column of Table II, S = 1° 50′; from the fourth column, L = 72.20 ft.; from the eighth column, l = 15.0 ft.; from the ninth column, $KE = Ka$ = 3.37 ft. Hence,

$$B K = 72.20 - 15.0 = 57.20 \text{ ft.,}$$

and $$B a = 57.20 - 3.37 = 53.83 \text{ ft.}$$

Finally, from the fifth column, r = 681.16 ft., and from the sixth column, d = 8° 25′.

(9) From Table III, the degree of curve corresponding to n = 9 is 8° 25′; since (Art. **28**) this is greater than the degree of curve of the main-track curve (3° 30′), the turnout rails and main-track rails will curve in opposite directions (Fig. 16). Therefore, the degree of curve of turnout is

$$8° 25' - 3° 30' = 4° 55'. \quad \text{Ans.}$$

From Table III, corresponding to n = 9 it is found that L = 72.20 ft. Ans.

(10) From Table III, the degree of curve for a No. 6 frog is 19° 59′. Therefore (Art. **29**), the degree of curve of the turnout is

$$19° 59' + 5° 0' = 24° 59'. \quad \text{Ans.}$$

From Table III, we find, corresponding to a No. 6 frog, L = 56.00 ft. Ans.

(11) To apply formulas **1** and **2**, Art. **30**, we have a = 13.0, g = 4.708, and n = 5. Substituting these values in formula **1**,

$$r' = 2 \times (13 - 4.708)\, 5^2 + \tfrac{1}{2} \times 13 = 421.10 \text{ ft.} \quad \text{Ans.}$$

From Table II, L = 47.08 ft. Therefore, formula **2**, Art. **30**, gives

$$KT = \frac{13.0 - 4.708}{4.708} \times 47.08 = 82.92 \text{ ft.} \quad \text{Ans.}$$

(12) First M is found by formula **2**, Art. **31**. Here a = 13.0 ft., g = 4.708 ft., n = 8, and R = radius of a 4° 30′ curve = 1,273.6 ft. Substituting these values in formula **2**,

$$\tan \tfrac{1}{2} M = \frac{13 - 4.708}{2 \times 1{,}273.6 + 13} \times 2 \times 8; \text{ whence } M = 5° 56'$$

From Table II, it is found that F = 7° 9′ 10″.

Substituting these values in formula **3**, Art. **31**,

$$r - 2.35 = \frac{(1{,}273.6 + 2.35) \sin 5° 56'}{\sin (7° 9' 10'' + 5° 56')}; \text{ whence } r = 584.92 \text{ ft.} \quad \text{Ans.}$$

The distance KT is found by formula **4** of the same article:

$$KT = 2 \times (1{,}273.6 + 2.35) \sin \tfrac{1}{2}(5° 56') = 132.07 \text{ ft.} \quad \text{Ans.}$$

(13) The method described in Art. **37** is applied. From Table II,

lead $BK = B'K'$, Fig. 23, = 65.92 ft. Ans.

Radius $O_1 Z = O_2 Z = r$ = 461.42 ft. Ans.

From formula **2**, Art. **37**,

$$\sin M = \sqrt{\frac{13.0}{461.42}};$$

whence M = 9° 39′ 46″. Ans.

From formula **3**,

$$BE = B'E' = 2 \times \sqrt{13.0 \times 461.42} = 154.90 \text{ ft.} \quad \text{Ans.}$$

(14) From Table III, lead Kb, Fig. 23, = 61.65 ft. Then, Bb = 65.92 − 61.65 = 4.27 ft. Therefore, by the formula given in Art. **38**,

$$be = b'e' = 154.90 - 2 \times 4.27 = 146.36 \text{ ft. Ans.}$$

(15) To apply the formula given in Art. **41**, we have, from Table III, $L' = 61.65$, $a = 13.0$, $n = 7$, and $g = 4.708$. Hence,

$$be = 2 \times 61.65 - \frac{13}{4 \times 7} + (13 - 2 \times 4.708)\,7 = 147.93 \text{ ft. Ans.}$$

(16) As shown in Art. **58**, each of the four frog angles will be 68° 30′. Ans.

Each of the rail lengths will be, by formulas **1** and **2**, Art. **58**,

$$4.708 \div \sin 68° \, 30' = 5.06 \text{ ft. Ans.}$$

(17) Formulas **1**, **2**, **3**, and **4**, Art. **60**, are applied. Here, $R = 881.95$ = radius of a 6° 30′ curve, $P = 68°$, and $\frac{1}{2}\,g = 2.35$ ft. Therefore,

$$\cos F = \frac{881.95 \cos 68° + 2.35}{881.95 + 2.35}; \text{ whence } F = 67° \, 53' \, 50''. \text{ Ans.}$$

$$\cos F_1 = \frac{881.95 \cos 68° - 2.35}{881.95 + 2.35}; \text{ whence } F_1 = 68° \, 13' \, 30''. \text{ Ans.}$$

$$\cos F_2 = \frac{881.95 \cos 68° - 2.35}{881.95 - 2.35}; \text{ whence } F_2 = 68° \, 6' \, 10''. \text{ Ans.}$$

$$\cos F_3 = \frac{881.95 \cos 68° + 2.35}{881.95 - 2.35}; \text{ whence } F_3 = 67° \, 46' \, 23''. \text{ Ans}$$

RAILROAD BUILDINGS AND MISCELLANEOUS STRUCTURES

(1) See Art. **3.**

(2) See Art. **4.**

(3) See Art. **7.**

(4) See Art. **8.**

(5) See Art. **8.**

(6) The form of the water tank shown in Fig. 7 is that of a frustum of a cone. The volume of the frustum of a cone is $(A + a + \sqrt{A\,a})\frac{h}{3}$ (see *Geometry*, Part 2). The area A of the lower base is $.7854 \times 16^2 = 201.06$ sq. ft. The area a of the upper base is $.7854 \times (14\frac{2}{3})^2 = 168.95$ sq. ft. Then,

$$V = (201.06 + 168.95 + \sqrt{201.06 \times 168.95}) \times \frac{16}{3} = 2{,}956.3 \text{ cu. ft.}$$

or, $$2{,}956.3 \times 7.48 = 22{,}113 \text{ gal. Ans.}$$

(7) See Art. **19.**

(8) See Arts. **23** and **24.** The amount of material required is as follows:

Number of posts, $660 \times 75 = 49{,}500$. Ans.
Boards, $3{,}300 \times 75 = 247{,}500$ ft. B. M. Ans.
Barb wire, $1{,}290 \times 75 = 96{,}750$ lb. Ans.
Staples, $40 \times 75 = 3{,}000$ lb. Ans.

Assuming 12 rods to be a day's work for one man, the labor required to build 75 miles of fence is

$$\frac{75 \times 320}{12} = 2{,}000 \text{ days' work. Ans.}$$

(9) See Art. **26.**

(10) See Art. **28.**

(11) (*a*) See Art. **33.**
(*b*) See Art. **36.**

(12) (*a*) See Art. **34.**
(*b*) See Art. **36.**

(13) See Art. **37.**

HIGHWAYS

(PART 1)

(1) (*a*) See Art. **2.**
(*b*) See Art. **3.**
(*c*) See Art. **4.**

(2) (*a*) See Art. **5.**
(*b*) See Art. **8.**

(3) (*a*) See Art. **12.**

(*b*) From the rule in Art. **12,** the width of the tire of a four-wheel wagon carrying a load of 9,000 lb. should be

$$9{,}000 \div 1{,}200 = 7.5 \text{ in.} \quad \text{Ans.}$$

(*c*) The width of the tire of a two-wheel cart carrying a load of $1\frac{1}{2}$ net tons should be

$$\frac{2{,}000 \times 1\frac{1}{2}}{300 \times 2} = 5 \text{ in.} \quad \text{Ans.}$$

(4) From the formula in Art. **18,**

$$t_o = \frac{1{,}200\sqrt{(5.2 - .2) \times .2}}{2.6 - .2} = 500 \text{ lb.} \quad \text{Ans.}$$

(5) As obtained from Table I, the value of c for a hard-rolled gravel roadway is $\frac{1}{30}$. By formula **5,** Art. **17,**

$$T = 10{,}000\left(\tfrac{4}{100} + \tfrac{1}{30}\right) = 733 \text{ lb.} \quad \text{Ans.}$$

(6) See Art. **19.**

(7) See Art. **21.**

(8) A speed of 5 mi. per hr. is equivalent to

$$5 \times 88 = 440 \text{ ft. per min.}$$

By the formula in Art. **20,** the tractive force of the horse is

$$20{,}000 \div 440 = 45.5 \text{ lb., nearly.} \quad \text{Ans.}$$

(9) See Art. **26.**

(10) (*a*) See Art. **27.**
(*b*) See Art. **28.**

(11) (*a*) and (*b*) See Art. **37.**
(*c*) See Art. **38.**

(12) (*a*) See Art. **54.**
(*b*) See Art. **55.**

(13) See Art. **56.**

(14) (*a*) See Art. **65.**
(*b*) See Art. **68.**

(15) (*a*) See Art. **69.**
(*b*) See Art. **76.**

HIGHWAYS

(PART 2)

(1) (*a*) See Art. **1.**
(*b*) See Art. **2.**

(2) See Art. **3.**

(3) See Art. **13.**

(4) See Art. **13.**

(5) See Art. **19.**

(6) (*a*) See Arts. **42** to **49.**
(*b*) See Art. **24.**
(*c*) See Art. **23.**

(7) (*a*) See Art. **28.**
(*b*) See Art. **29.**

(8) See Art. **25.**

(9) See Art. **53.**

(10) See Art. **54.**

(11) See Art. **45.**

(12) Read Arts. **43** to **49.**

(13) See Art. **33.**

(14) Read Arts. **34, 35,** and **36.**

(15) Read Arts. **37, 38,** and **39.**

PAVEMENTS

(1) See Art. **2**.

(2) (*a*) See Art. **12**.
(*b*) and (*c*) See Art. **20**.

(3) The area of the piece of pavement considered is $10 \times 1 = 10$ sq. yd. From Table III, the mean cost of granite-block pavement is \$2.80 per sq. yd., to which must be added \$.90 for the cost of a concrete foundation. The final value of the foundation and surface material is (Art. **15**) \$.90 + \$.80 = \$1.70. From Table II, the mean life of a granite-block pavement is 21 yr. Substituting these values in the formula of Art. **14**,

$$k = \frac{10(3.70 - 1.70)}{21} + 10 \times .04 \times 3.70 = \$2.432. \quad \text{Ans.}$$

(4) (*a*) The area of the piece of pavement considered is $\frac{36}{3} \times 1 = 12$ sq. yd. From Table II, the mean life of asphalt pavement is 12 yr. From Table III, the mean cost of asphalt pavement on concrete foundation is \$3 per sq. yd. The final cost of the foundation and surface material is (Art. **15**) \$.90 + \$.10 = \$1. Substituting in the formula of Art. **14**,

$$k = \frac{12(3.00 - 1.00)}{12} + 12 \times .04 \times 3 = \$3.44.$$

From Table V, the annual cost of maintenance is $12 \times .09 = \$1.08$.

From Table VI, the annual cost for cleaning and sprinkling is $12 \times .02 = \$.24$.

From Table VII, the annual service cost is $12 \times .15 = \$1.80$.

From Table VIII, the estimated annual cost for damages is $12 \times .02 = \$.24$.

The total annual cost is, therefore,

$$3.44 + 1.08 + .24 + 1.80 + .24 = \$6.80. \quad \text{Ans.}$$

(*b*) Substituting the given values in the formula of Art. **23**,

$$d_t = \frac{\frac{1}{2} \times 2{,}460 + 2 \times 1{,}115 + 4 \times 260}{5} = 900 \text{ T.}$$

The total annual cost has been found to be \$6.80, or 680 ct., and d_t to be 900 T. Substituting in the formula of Art. **25**,

$$t_y = \frac{680}{365 \times 900 \times 1} = .00207 \text{ ct.} \quad \text{Ans.}$$

(5) See Art. **36**.

(6) See Art. **39**.

(7) See Art. **40**.

(8) (*a*) See Art. **45**.
(*b*) and (*c*) See Art. **46**.
(*d*) See Art. **47**.

(9) See Art. **48**.

(10) See Art. **34**.

(11) See Art. **60**.

(12) (*a*) See Art. **66**.
(*b*) See Art. **96**.

(13) (*a*) See Art. **70**.
(*b*) See Art. **71**.
(*c*) and (*d*) See Art. **73**.

(14) See Art. **74**.

(15) See Art. **77**.

(16) (*a*) and (*b*) See Art. **81**.
(*c*) and (*d*) See Art. **82**.

(17) (*a*) See Art. **87**.
(*b*) See Art. **88**.

(18) See Art. **91**.

(19) (*a*) and (*b*) See Art. **94**.

CITY SURVEYING

(1) See Art. **1.**

(2) See Art. **2.**

(3) To apply formula **2**, Art. **5**, we have $l = 488.76$, $c = .0000065$, $t = 50$, and $t_0 = 62$. Substituting in the formula,

$$l_0 = 488.76 + .0000065\ (50 - 62)\ 488.76 = 488.722 \text{ ft. Ans.}$$

(4) To apply formula **3**, Art. **6**, we have $l = 906.56$, $P = 15$, $E = 28{,}000{,}000$, and $A = .002$. Substituting in the formula,

$$l_0 = 906.56 + \frac{15}{28{,}000{,}000 \times .002} \times 906.56 = 906.80 \text{ ft. Ans.}$$

(5) To apply formula **2**, Art. **7**, we have $n = 5$, $w = .008$, $L_0 = 100$, and $P = 20$. Substituting in the formula,

$$n\,s = \frac{5 \times .008^2 \times 100^3}{24 \times 20^2} = .033 \text{ ft. Ans.}$$

(6) To apply the formula in Art. **8**, we have $w = .007$, $L_0 = 100$, $A = .002$, and $E = 28{,}000{,}000$. Substituting in the formula,

$$P = \sqrt[3]{\frac{.007^2 \times 100^2 \times .002 \times 28{,}000{,}000}{24}} = 10.5 \text{ lb. Ans.}$$

(7) To apply formula in Art. **10**, we have $l = 250$ and $h = 104.48 - 100 = 4.48$. Substituting in the formula,

$$d = 250 - \frac{4.48^2}{2 \times 250} = 249.96 \text{ ft. Ans.}$$

(8) See Art. **11.**

(9) See Art. **14.**

(10) See Art. **16.**

(11) Let l_1 represent the measured length of the line and t_1 the temperature in summer; also l_2 = measured length of line, and t_2 = temperature in winter. From formula **2**, Art. **5**,

$$l_0 = l_1 + c\ (t_1 - t_0)\ l_1 \text{ and } l_0 = l_2 + c\ (t_2 - t_0)\ l_2$$

Equating these two values of l_0 and solving for c,

$$c = \frac{l_2 - l_1}{(t_1 - t_0)\,l_1 - (t_2 - t_0)\,l_2}$$

Here, $l_2 = 400.045$, $l_1 = 399.871$, $t_1 = 80$, $t_2 = 10$, and $t_0 = 62$. Substituting in the foregoing equation,

$$c = \frac{400.045 - 399.871}{(80 - 62)399.871 - (10 - 62)400.045} = .0000062. \quad \text{Ans.}$$

(12) (*a*) The mean value of the distance is

$$M = 903 + \frac{.49 + .48 + .50 + .47}{4} = 903.485 \text{ ft.} \quad \text{Ans.}$$

(*b*) The probable error is found by the formula in Art. **17.**

$$\begin{aligned}
v_1 &= 903.485 - 903.49 = -.005\\
v_2 &= 903.485 - 903.47 = .015\\
v_3 &= 903.485 - 903.50 = -.015\\
v_4 &= 903.485 - 903.47 = .015
\end{aligned}$$

$$\Sigma v^2 = (-.005)^2 + (.015)^2 + (-.015)^2 + (.015)^2 = .0007$$

Substituting in the formula,

$$p = \pm .6745\sqrt{\frac{.0007}{4\,(4 - 1)}} = \pm .005 \text{ ft.} \quad \text{Ans.}$$

(13) Read Art. **22.**

(14) See Art. **28.**

(15) See Art. **53.**

(16) See Arts. **23** and **24.**

(17) Read Art. **40.**

(18) Read Arts. **50** and **51.**

CITY STREETS

(1) (*a*) By substituting the width of roadway and per cent. of grade in the formula of Art. **7**, and using the value of q for common earth roadways, as given in Table I, the required amount of crown is found to be equal to

$$\frac{16}{40} + \frac{16 \times 5\left(\frac{70}{40} - 1\right)}{800} = .475 \text{ ft.} \quad \text{Ans.}$$

(*b*) By substituting in the formula the value q as given in Table I for ordinary gravel roadways, and retaining the same width and grade as in (*a*), the required amount of crown is found to be equal to

$$\frac{16}{50} + \frac{16 \times 5\left(\frac{70}{50} - 1\right)}{800} = .360 \text{ ft.} \quad \text{Ans.}$$

(*c*) By substituting the width and rate of grade in the formula, and retaining the value q for gravel roadways, the required amount of crown is found to be equal to

$$\frac{20}{50} + \frac{20 \times 4\left(\frac{70}{50} - 1\right)}{800} = .440 \text{ ft.} \quad \text{Ans.}$$

(2) (*a*) By substituting in the formula of Art. **7** the width of roadway, the per cent. of grade, and the value of q as given in Table I for wooden-block pavement, the required amount of crown is found to be equal to

$$\frac{28}{70} + \frac{28 \times 3\left(\frac{70}{70} - 1\right)}{800} = .400 \text{ ft.} \quad \text{Ans.}$$

(*b*) By substituting the amount of crown, width of roadway, and value of the abscissa, for c, w, and x, respectively, in the formula of Art. **10**, the value of the ordinate to the surface line of the cross-section at a distance of 3.5 ft. from the center is

$$\frac{4 \times .4 \times 3.5^2}{28^2} = .025 \text{ ft.} \quad \text{Ans.}$$

(*c*) In like manner, the ordinate to the surface line of the cross-section at a point distant 7 ft. from the center is

$$\frac{4 \times .4 \times 7^2}{28^2} = .1 \text{ ft.} \quad \text{Ans.}$$

(3) (*a*) By substituting in the formula of Art. **7** the width of roadway, per cent. of grade, and value of q as given in Table I

for first-class asphalt pavement, the required amount of crown is found to be

$$\frac{48}{120} + \frac{48 \times 1.6\left(\frac{70}{120} - 1\right)}{800} = .36 \text{ ft.} \quad \text{Ans.}$$

(*b*) By substituting the amount of crown, width of roadway, and length of central curve in formula **1** of Art. **11**, the rate of the lateral slope on the uniformly sloping portion of the roadway is found to be

$$\frac{4 \times .36}{2 \times 48 - 6} = .016. \quad \text{Ans.}$$

(*c*) By substituting the rate of slope, length of central curve, and the abscissa in formula **4** of Art. **11**, the ordinate to the surface line at a point distant 3 ft. from the center is found to be

$$.016 \times \left(3 - \tfrac{6}{4}\right) = .024 \text{ ft.} \quad \text{Ans.}$$

(*d*) In like manner, the ordinate to the surface line at a point distant 6 ft. from the center is found to be

$$.016 \times \left(6 - \tfrac{6}{4}\right) = .072 \text{ ft.} \quad \text{Ans.}$$

(*e*) In like manner, also, the ordinate to the surface line at a point distant 12 ft. from the center is found to be

$$.016 \times \left(12 - \tfrac{6}{4}\right) = .168 \text{ ft.} \quad \text{Ans.}$$

(4) (*a*) By substituting in the formula of Art. **7** the width of roadway, the per cent. of grade, and the value of *q*, as given in Table I for well-laid brick pavement, the required amount of crown is found to be equal to

$$\frac{40}{100} + \frac{40 \times 2 \times \left(\frac{70}{100} - 1\right)}{800} = .37 \text{ ft.} \quad \text{Ans.}$$

(*b*) By substituting in formula **1** of Art. **11** the amount of crown, width of roadway, and length of central curve, the rate of lateral slope for the uniformly sloping portion of the roadway surface is found to be

$$\frac{4 \times .37}{2 \times 40 - 6} = .02. \quad \text{Ans.}$$

(5) See Art. **23**. The edge of the sidewalk adjacent to the curb has the same elevation as the curb, which, in a street having a symmetrical cross-section, will generally be the same as the street grade, or, in this case, 124.62 ft. If the sidewalk is 12 ft. wide and has a lateral slope of 2 per cent., the elevation of the edge adjacent to the building line will be

$$124.62 + \frac{2 \times 12}{100} = 124.86 \text{ ft.} \quad \text{Ans.}$$

(6) (*a*) See Fig. 20. As both streets have a rising grade toward the curb angle *a*, this angle will be at a distance above the center of intersection equal to the rise of the grade line in half the width of the street, or $3 \times 20 \times .01 = .6$ ft. As this amount of rise will occur in each street, the difference between the elevations of this curb angle, as estimated from the two grade lines, will be zero. Ans.

(*b*) Likewise, as both streets have a falling grade toward the curb angle *b*, at the same rate and through the same distance, the difference between the elevations of the curb angle, as estimated from the two grade lines, will also be zero. Ans.

(*c*) From the center of intersection to a point opposite the curb angle *c*, the grade line of the street *A B* falls the amount $3 \times 20 \times .01 = .6$ ft., and the grade line of the street *C D* rises the same amount. Hence, the difference between the elevations of this curb angle, as estimated from the two grade lines, is $.6 + .6 = 1.2$ ft. Ans.

(*d*) Likewise, from the center of intersection to a point opposite the curb angle *d*, the grade line of the street *A B* rises .6 ft. and that of *C D* falls the same amount. Hence, the difference between the elevations of this curb angle also, as estimated from the two grade lines, is $.6 + .6 = 1.2$ ft. Ans.

(7) (*a*) The width of roadway is 40 ft. The difference between the elevations of the curbs is

$$\frac{40 \times 1}{100} = .4 \text{ ft. Ans.}$$

(*b*) From question 4 (*b*), the rate of slope on the uniformly sloping portion of the roadway surface is known to be .02. Hence, by formula **1** of Art. **48**, the required eccentricity is

$$\frac{.4}{2 \times .02} = 10 \text{ ft. Ans.}$$

(*c*) The length of the central curve is 6 ft. By applying formula **2** of Art. **48**, the value of d_m, the greatest difference between the elevations of the curbs to which the formula for eccentricity will correctly apply, is found to be $.02 \times (40 - 6) = .68$ ft. As the actual difference (1 ft.) between the elevations of the curbs is greater than this, the formula for eccentricity of crown will not apply. Ans.

(*d*) As given by the formula of Art. **49**, the rate of uniform slope across the roadway will be $\frac{1}{40} = .025$. Ans.

(8) (*a*) By reference to question 3, it is found that the width of roadway is 48 ft.; the length of the central curve is 6 ft., and the rate of slope for the uniformly sloping portion of the roadway [Ans. (*b*)] is .016. Hence, from formula **2** of Art. **48**, the greatest difference between the elevations of the curbs to which the formula for eccentricity will correctly apply is

$$.016 \times (48 - 6) = .672 \text{ ft. Ans.}$$

(*b*) From formula **1** of Art. **48**, the eccentricity of crown necessary to give a difference of .672 ft. between the elevations of the curbs is found to be

$$\frac{.672}{2 \times .016} = 21 \text{ ft. Ans.}$$

(*c*) From formula **1** of Art. **48**, the eccentricity of crown necessary to give a difference of .6 ft. between the elevations of the curbs is found to be

$$\frac{.6}{2 \times .016} = 18.75 \text{ ft. Ans.}$$

(*d*) The rate of the grade of the intersecting street will be

$$\frac{.6 \times 100}{48} = 1.25 \text{ per cent. Ans.}$$

(9) See Art. **2**.

(10) See Art. **3**.

(11) (*a*) See Art. **15**. (*b*) See Art. **16**.

(12) Read Arts. **25** to **32**, inclusive.

(13) See Art. **42**.

(14) See Art. **52**.

(15) See Art. **56**.

(16) See Art. **57**.

INDEX

NOTE.—All items in this index refer first to the section, and then to the page of the section. Thus, "Alleys, §63, p29," means that alleys will be found on page 29, section 63.

A

Abrasion, Resistance of paving materials to, §62, p20.
Absorptive capacity of paving materials, §62, p20.
Abutments for trestles, §56, p34.
in preliminary railroad estimates, §55, p40.
Accuracy and precision, Difference between, §63, p16.
of earthwork computations, §54, pp15, 58.
Adjustment of angles in a triangle, §63, p12.
of city bench marks, §63, p49.
of gradients in railroad location, §55, p45.
Advantages of transition spiral, §53, p12.
Adverse possession, §63, p20.
Advertisement for common roadbeds, §61, p23.
Air resistance in common roads, §60, p3.
Alinement in railroad preliminary survey, §55, p21.
of track, Maintenance of, §57, p42.
Alleys, §63, p29.
Allowance for ditches in earthwork computation, §54, p44.
for expansion of rails, §57, p33.
for overhaul, §54, p70.
Anchor block of a spring frog, §58, p15.
Angle bars, Cost of, §57, p21.
bars for rails, §57, p13.
bars per mile of track, §57, p22.
between chord and tangent to a spiral, §53, p17.
Deflection, for any point of a spiral, §53, p17.
Frog, §58, p16.
of deflection, §53, p13.
of deviation, §53, p13.
of repose, §60, p14.
-splice joint, §57, p13.
Angles, Curb, §64, p29.
Measurement of, by method of repetition, §63, p11.
of a triangle, Adjustment of, §63, p12.
Angular measurements in city surveying, §63, p8.
measurements, Precision in, §63, p16.
Area of irregular earthwork section, §54, p27.
Areas of end sections in side-hill earthwork, §54, p34.
Artificial asphalt, §62, p26.
Ash cars, §59, p43.
conveyers, §59, p45.
-pits, §59, p43.
Asphalt, §62, p22.
Artificial, §62, p26.
-block pavements, Construction of, §62, p50.
cement, §62, p25.
Composition of, §62, p23.
Crude, §62, p24.
Flux for, §62, p25.
for paving, Quality of, §62, p25.
for sidewalks, §64, p22.
General properties of, §62, p23.
lakes §62, p22.
Land, §62, p22.
Laying of, for pavements, §62, p45.
Machines for testing, §62, p25.
Natural, §62, p48.
pavement adjoining railway track, §62 p47.
pavement, Drawing of, §65, p16.
pavements, Construction of, §62, p42.
pavements, Gutters for, §62, p46.
paving blocks §62, p50.
Paving, Ingredients for, §62, p43
Pure, Use of, for gutters, §62, p46.
Refined, §62, p24.
Rock, §62, pp24, 48.
sidewalks, Sheet-, §64, p26.
Sources of supply of, §62, p22.
tiles, §62, p50.
-tile sidewalks, §64, p27.

Asphalte, §62, p24.
Asphaltene, §62, p23.
Asphaltic cement, §62, pp25, 27.
Asphaltina, §62, p26.
Asphaltum, §62, pp22, 24.
Average earthwork haulage, §54, p69.
-end-area formula, §54, p16.
Axle friction, §60, p3.
Axmen in railroad preliminary survey, §55, p27.

B

Backing up in railroad preliminary survey, §55, p33.
Ballast, Materials used for, §57, p1.
Broken-stone, §57, p1.
Broken-stone, Representation of, §65, p8.
Cinder, §57, p2.
Cost of, §57, p19.
Gravel, §57, p2.
Gravel, Representation of, §65, p9.
Laying of, §57, p24.
Mud, §57, p3.
of railroad track, §57, p1.
Placing of new, in old track, §57, p45.
Shell, §57, p3.
Slag, §57, p2.
Bank-bent connection between trestle and embankment, §56, p36.
Banks, Spoil, §60, p41.
Bar coupler, §59, p38.
Bars, Angle, Cost of, §57, p21.
Angle, for rails, §57, p13.
Angle, per mile of track, §57, p22.
Base, Bituminous, for sheet-asphalt pavement, §62, p42.
City, §63, p49.
Hydraulic, for sheet-asphalt pavement, §62, p42.
of rail, §57, p8.
Basins, Catch, Location of, §64, p39.
Battered piles, §56, p6.
posts in trestlework, §56, p6.
Batter posts for framed bents, Framing of, §56, p17.
Bays, Refuge, in trestles, §56, p37.
Belgian-block pavements, §62, p31.
Bench marks City, §63, p49.
marks, City, Adjustment of, §63, p49.
marks in railroad-location survey, §55, p55.
Bender, Rail, §57, p30.
Bent, Framed, §56, p5.
Pile, §56, pp5, 7.
Trestle, §56, p2.
Bents, Framed, §56, p12, §65, p10.
Kinds of, §56, p5.
Locating of, in trestlework, §56, p38.
Trestle, §65, p10.
Bids for common roads, Advertisements for, §61, p23.
Binder course for sheet-asphalt pavement §62, p42.
Bitulithic pavement, §62, p27.
pavements, Construction of, §62, p52.
Bitumen, §62, p22.
Bituminous base for sheet-asphalt pavement, §62, p42.
cement, §62, p27.
concrete, §62, p29.
limestone, §62, p24.
rock, §62, p48.
sandstone, §62, p24.
Blast, Exploding a, §54 p75.
Blasting, §54, p73.
Cost of, §54, p76.
Block, Anchor, of a spring frog, §58, p15.
books, §63, p52.
cards, §63, p53.
corners, Elevations of, §64, p38.
Head-, of a switch, §58, p2.
Packing-, in trestle work, §56, p6.
Blocks, Asphalt paving, §62, p50.
City, Size of, §63, p28.
Granite paving, §62, p32.
Wooden paving, §62, p37.
Wooden paving, Chemical treatment of §62, p41.
Wooden paving, Expansion of, §62, p40.
Board, Sighting, §57, p41.
Bolt spikes, §56, p32.
Bolts, Drift, §56, p32.
Packing-, in trestlework, §56, p6.
Track, §57, p18.
Track, Cost of, §57, p21.
Track, in 200-pound keg, §57, p22.
Track, per mile of track, §57, p22.
used in trestlework, §56, p33.
Bond for construction of common roads, §61, p28.
Books, Block, §63, p52.
Note, for city work, §63, p55.
Border stones, §61, p16.
Borrow pits, §54, p42.
Bowen's machine for testing asphalt, §62, p25.
Box drains, §61, p4.
Brace, Longitudinal, in trestlework, §56, p6.
Braced piles, §56, p6.
Braces, Rail, §57, p16.
Bracing for trestles, §56, p28.
Longitudinal, for trestles, §56, p29.
of railroad fences, §59, p29.
Brakes, Water, §61, p9.
Branch lines in railroad preliminary survey, §55, p34.

Breaker, Jaw, §61, p14.
Breakers, Rock, §61, p14.
Brick pavements, Construction of, §62, p52.
Paving, §62, p27.
sidewalks, §64, p24.
Bricks for sidewalks, §64, p22.
Paving, Dimensions of, §62, p53.
Paving, Laying of, §62, p54.
Bridge, Spiral, for developing a railroad line, §55, p16.
stones for city streets, §64, p28.
Bridges in preliminary railroad estimates, §55, p40.
Broken-stone ballast, §57, p1.
stone for common roads, §61, p13.
-stone pavements, §62, p35.
-stone roads, §61, p11.
-stone roads, Specifications for, §61, p23.
stone, Screens for, §61, p15.
Building line, §63 p17.
lots, Laying out of, §63, p30.
Buildings, Railroad section, §59, p3.

C

Cap in trestlework, §56, p5.
of a trestle, §65, p13.
Capping in framed bents, §56, p19.
of piles in pile bents, §56, p9.
Caps, Split, for piles, §56, p11.
Card index of city surveys, §63, p56.
Cards, Block, §63, p53.
Care of track, §57, p45.
Cars, Ash, §59, p43.
Depressed tracks for cinder, §59 p44.
Carts, Spreading, §61, p17.
Cast-iron pipe joint, Drawing of, §65, p22.
Catch basins, Location of, §64, p39.
-water drains, §61, p3.
Cattle guards, Covered-pit, §59, p40.
guards for railroads, §59, p39.
guards, Open-pit, §59, p40.
guards, Surface, §59, p41.
Cement asphalt, §62, p25.
Asphaltic, §62, pp25, 27.
Bituminous, §62, p27.
Census of traffic tonnage, §62, p15.
Traffic, §62, p15.
Center of curvature of any curve, §53, p4.
of gravity, Eccentricity of, in earthwork, §54, p47.
Certificate for city-lot survey, §63, p23.
Chaining in railroad preliminary survey, §55, p24.
on sloping ground, §63, p7.
Charcoal roads, §61, p20.
Chemical composition of rails, §57, p12.
treatment of ties, §57, p7.
Chemical—(Continued)
treatment of wooden paving blocks, §62, p41.
Chert roads, §61, p20.
Chief of party in railroad preliminary survey, §55, p21.
Churn drilling, §54, p74.
Cinder ballast, §57, p2.
cars, §59, p43.
Circle, Osculating, of any curve §53, p4.
City base, §63, p49.
datum, §63, p49.
-lot survey, Certificate for, §63, p23.
-lot survey, Plot of, §63, p23.
lots, Description of, §63, p17.
lots, Grading of, §63, p39.
lots, Relocation of, §63, p21.
lots, Survey of, §63, p17.
monuments, §63, p45.
office records, §63, p52.
surveying, §63, p1.
surveying, Instruments used in, §63, p1.
surveys, Grading, §63, p37.
surveys, Private, §63, p55.
surveys, Subdivisional, §63, p26.
transit, §63, p8.
Classification of railroad routes, §55, p10.
of trestles, §56, p2.
Clay soils, Roads in, §61, p10.
Cleaning and sprinkling of pavements, Cost of, §62, p11.
Clearing in trestle construction, §56, p46.
of right of way, §54, p5.
Coaling stations, Railroad, §59, p19.
Coal tar, §62, p26.
Coat, Cushion, for asphalt pavement, §62, p45.
Cushion, for brick pavement, §62, p53
Cushion, for granite-block pavement, §62, p32.
Cushion, for wooden pavement, §62, p37.
Surface, for asphalt pavement, §62, p45.
Cobblestone pavements, §62, p30.
Coefficient of expansion of steel tapes, §63, p3.
of rolling friction, §60, p5.
Temperature, of steel tapes, §63, p3.
Collision of wagon wheels, §60, p10.
Columns, Water, §59, p16.
Common roads, Construction profiles for, §60 p37.
Comparison of routes for common roads, §60, p27.
Compass, Use of, in railroad preliminary survey, §55, p20.
Compensation for curvature in railroad location, §55, p50.

Compound sections, Earthwork, §54, p13.
 sections, Volume between, §54, p39.
Computation of volume for earthwork, §54, p15.
Computations, earthwork, Accuracy of, §54, p58.
Concrete, Bituminous §62, p29.
 curbing, §64, p15.
 for pavements, §62, p28.
 gutters, §64, p15.
 Tar, for sidewalks, §64, p22.
Connecting curve between parallel curved tracks, §58, p37.
 curve between parallel straight tracks, §58, p35.
 curves, Track, §58, p35.
Connection of freight-yard tracks with main tracks, §59, p37.
 of trestle with embankment, §56, p34.
 rod of a switch, §58, p3.
Consequent damages in pavements, §62, p12.
Construction of asphalt-block pavements, §62, p50.
 of asphalt pavements, §62, p42.
 of bitulithic pavements, §62, p52.
 of brick pavements, §62, p52.
 of curbs, §64, p12.
 of pavements, §62, p30.
 of pile bents, §56, p8.
 of railroad fences, §59, p28.
 of roads, §61, p9.
 of rock-asphalt pavements, §62, p48.
 of wooden pavements, §62, p36.
 profile for a common road, §60, p37.
Continuous-rail joint, §57, p15.
Contour, Grade, §55, p21.
Contract for construction of common roads, §61, p26.
Controlling points in railroad location, §55, p3.
Conveyers, Ash, §59, p45.
Coordinates for cross-section of street roadway, §64, p7.
 of spiral, §53, p18.
Corbels in trestle floor, §56, p20.
Corduroy roads, §61, p20.
Corners, Block, Elevations of, §64, p38.
 Curb, §64, p29.
Correction for curvature in earthwork: General case, §54, p45.
 for curvature in side-hill earthwork, §54, p51.
 of tape for pull, §63, p4.
 of tape for sag, §63, p5.
 of tape for temperature, §63, p3.
 Prismoidal, §54, p17.
 Prismoidal, for three-level section prismoid, §54, p20.
Correction—(Continued)
 Prismoidal, for triangular prismoid, §54, p17.
 t, for a spiral, §53, p20.
 x, for a spiral, §53, p19.
Corrections to linear measurements in city surveying, §63, p3.
Corresponding points, §53, p29.
Cost of angle bars, §57, p21.
 of ballast, §57, p19.
 of blasting, §54, pp73, 76.
 of city surveys, Record of, §63, p57.
 of cleaning and sprinkling of pavements, §62, p11.
 of common-road construction, §61, p24.
 of drain pipe for common roads, §61, p25.
 of earthwork, §54, p71.
 of embankments and trestles compared, §56, p2.
 of excavation for common roads, §61, p24.
 of maintenance, Influence of, on railroad location, §55, p6.
 of maintenance of pavements, §62, p10.
 of masonry for common roads, §61, p25
 of pavements, §62, p8.
 of granite-block pavement, §65, p15.
 of pavements, Basis for estimating comparative, §62, p13.
 of railroad construction, Preliminary estimate of, §55, p36.
 of rails, §57, p20.
 of rail spikes, §57, p24.
 of service of pavements, §62, p12.
 of stone for common roads, §61, p25.
 of switching engines, §59, p33.
 of Telford foundation, §61, p25.
 of ties, §57, p20.
 of track, §57, p19.
 of track bolts, §57, p21.
 of traffic in streets and roads, §62 p17.
 of wagon transportation, §60, p2.
Counter-posts in trestles, §56, p29.
Coupler, Bar, §59, p38.
Course, Binder, for sheet-asphalt pavement, §62, p42.
Covered-pit cattle guards, §59, p40.
Creosoted trestles, Specifications for, §56, p48.
Crib connection between trestle and embankment, §56, p35.
Cribs for framed bents, §56, p15.
Cross-country route, §55, p13.
 -over between parallel curved tracks, §58, p49.
 -over between parallel straight tracks, §58, p44.
 -overs, §58, p44.

Cross—(Continued)
-section, Eccentricity of, in earthwork, §54, p45.
-section of common roads, §60, p18.
-section of street roadway, §64, p2.
-section of street roadway, Coordinates for, §64, p7.
-sections of railroad roadbeds, §65, p7.
-sections of T rails, §65, p2.
-sectioning, §54, p9.
-sectioning, Notes for, §54, p14.
-sectioning of borrow pits, §54, p42.
Crossing stones for city streets, §64, p28.
Track, §58, p62.
Crossings, Track, Formulas for, §58, p63.
Cross-tie in a trestle, §56, p6.
Crow, Jim, §57, p30.
Crown at street intersections, §64, p36.
Curving, §64, pp6, 7.
Eccentricity of, §64, p35.
Form of, §64, p6.
Height of, §64, p3.
of street roadways, §64, p3.
Sloping, §64, pp6, 8.
Symmetrical, §64, p7.
Crowns, Eccentric, §64, p33.
Crude asphalt, §62, p24.
Crushers, Rock, §61, p14.
Rotary, §61, p14.
Crushing strength of paving materials, §62, p20.
Culverts in preliminary railroad estimates, §55, p40.
Pipe, for common roads, Specifications for, §61, p30.
Curb, §64, p1.
angles, §64, p29.
corners, §64 p29.
Curbing, §64, p12.
Concrete, §64, p15.
Stone, §64, p13.
Curbs, §64, p12.
Curbstones, §64, p13.
Curvature, Center of, of any curve, §53, p4.
Compensation for, in railroad location, §55, p50.
Correction for, in side-hill earthwork, §54, p51.
correction in earthwork: General case, §54, p45.
Influence of, on railroad location, §55, p6.
in railroad location, §55, p48.
of any curve, §53, p5.
of any curve, Radius of, §53, p4.
Curve, Center of curvature of a, §53, p4.
Connecting, between parallel curved tracks, §58, p37.
Curve—(Continued)
Connecting, between parallel straight tracks, §58, p35.
Degree of, §53, p5.
Mass, for earthwork haulage, §54, p65.
Osculating circle of any, §53, p4.
Point of, of a spiraled curve, §53, p19.
Radius of curvature of any, §53, p4.
Tangent to any, §53, p5.
Transition, §53, p3.
Vertical, at a sag, §55, p63.
Vertical, at a spur, §55, p62.
Curved protractor, §55, p43.
track, §57, p34.
track, Maintenance of, §57, p42.
tracks, Cross-over between parallel, §58, p49.
Curves for common roads, §60, pp21, 40.
Track connecting, §58, p35.
Trestles on, §56, p30.
Vertical, §55, p61.
Widening of gauge in, §57, p38.
Curving crown, §64, pp6, 7.
of rails, §57, p35.
Cushion coat for asphalt pavements, §62, p45.
coat for brick pavement, §62, p53.
coat for granite-block pavement, §62, p32.
coat for wooden pavement, §62, p37.
Cut, §54, p1.
Curvature correction for, in side-hill earthwork, §54, p51.
spikes, §56, p32.
Transition from, to fill, §54, p38.
Cuts, Slope ratio in, §54, p3.
Cutting off of piles for pile bents, §56, p9.

D

Dam, Earth, Drawing of, §65, p18.
Timber-crib rock-filled, Drawing of, §65, p20.
Damages, Consequent, in pavements, §62, p12.
Contractor's liability for, in trestle construction, §56, p50.
Dams (Plate), §65, p18.
Dapping in trestlework, §56, p6.
Datum, City, §63, p49.
Deceptive appearances in hilly ground, §55, p10.
Deck of a trestle, §65, p10.
Deflection angle for any point of a spiral, §53, p17.
Angle of, §53, p13.
Degree of curve, §53, p5.
of curve at any point of a spiral, §53, p9.
of curve of spiral, Unit, §53, p9.
Departing tracks for freight yards, §59, p37.

Depressed tracks for cinder cars, §59, p44.
Depth of a stake, §54, p7.
 of center stake, §54, p7.
Design of freight yards, §59, p33.
 of trestles §56, p45.
Details of trestle construction, §56, p32.
Detonating powder, §54, p74.
Development of a railroad line, §55, p15.
Deviation, Angle of, §53, p13.
Diagram, Mass, for earthwork haulage, §54, p65.
Dimensions of standard rails, §57, p9.
 of track crossings, §58, p63.
Distance between framed bents, §56, p20.
 Effect of, on railroad location, §55, p5.
 External, to a circular curve, §53, p35.
Distributing of ties, §57, p24.
Ditches, Allowance for, in earthwork computations, §54, p44.
 for highways, §61, p3.
 Side, for highways, §61, p8.
Ditching for track drainage, §54, p5.
Dotted lines, Use of, in drawings, §65, p13.
Dowels, §56, p33.
Dow's machine for testing asphalt, §62, p25.
Drain pipe for common roads, Cost of, §61, p25.
Drainage at street intersections, §64, p39.
 of common roads, §61, p1.
 of track, Ditching for, §54, p5.
 Subsoil, §61, p1.
 Surface, §61, p1.
Drains, Arrangement of subsoil, §61, p6.
 Box, §61, p4.
 Catch-water, §61, p3.
 for highways, §61, p3.
 for highways, General conditions to be considered in the construction of, §61, p6.
 Gravel, §61, p5.
 Miter, §61, p7.
 Tile, §61, p5.
Drawing of asphalt pavement, §65, p16.
 of cast-iron pipe joint, §65, p22.
 of cross-section of macadam road, §65, p17.
 of earth dam, §65, p18.
 of granite-block pavement, §65, p15.
 of intersection of paved streets, §65, p14.
 of railroad cross-section, §65, p7.
 of timber-crib rock-fill dam, §65, p20.
 of timber trestle, §65, p10.
 of T-rail cross-sections, §65, p2.
 plates, Directions for making, §65, p2.
 plates, General description of, §65, p1.
Drawings for trestlework, §56, p46.
Drift bolts, §56, p32.
Drilling, §54, p74.
Drip holes, §56, p17.
Durability of pavements, §62, p5.
 of ties, §57, p5.
Duties of city surveyors concerning encroachments, §63, p20.
Dynamite, Use of, in blasting, §54, p73.

E

Earthwork compound sections, §54, p13.
 Computation of volumes for, §54, p15.
 computations, Accuracy of, §54, p15, 58.
 Correction for curvature in, §54, p45.
 Cost of, §54, p71.
 Cost of hauling, §54, p71.
 for common roads, §60, p41.
 in common roads, Specifications for, §61, p29.
 in lot grading, §63, p40.
 in preliminary railroad estimates, §55, p37.
 in street grading, §63, p43.
 Irregular sections in, §54, p27.
 level cuttings, §55, p38.
 Loading of material in, §54, p71.
 Loosening of material in, §54, p71.
 prismoids, §54, p16.
 sections, Three-level, §54, p20.
 Shrinkage of, §54, p55.
 Side-hill, §54, p34.
 Spreading of, §54, p72.
 surveys, §54, p1.
 Volume of, in side-hill work, §54, p36.
Eccentric crowns, §64, p33.
Eccentricity of earthwork cross-section, §54, p45.
 of center of gravity in earthwork, §54, p47.
 of roadway crown, §64, p35.
Economics of pavements, §62, p8.
 of railroad location, §55, p1.
Economy of pavements, §62, p7.
 of routes, Relative, in railroad location, §55, p2.
Edge stones, §61, p16.
Elevations of block corners, §64, p38.
Embankment, Connection of trestle with, §56, p34.
Embankments and trestles, Comparative cost of, §56, p2.
 for common roads, §60, p42.
 Width of, §54, p4.
Encroachments, §63, p19.
Engine houses, §59, p8.
Engines, Switching, Cost of, §59, p33.
Equality station, §55, p36.
Equation, Level-section, §54, p10.
Equations, Slope-stake, §54, p10.
Equipment for railroad preliminary survey, §55, p19.
Erection of trestles, §56, p39.

Error, Probable, §63, p13.
Errors in earthwork computations, §54, pp15, 58.
Estimate, Preliminary, for a railroad, §55, p36.
preliminary railroad, Form of, §55, p41.
Excavation for common roads, Cost of, §61, p24.
of rock for common roads, Specifications for, §61, p30.
Excavations, Width of, §54, p4.
Excessive fall in common roads, §60, p29.
Expansion, Coefficient of, of steel tapes, §63, p3.
of rails, §57, p33.
of wooden paving blocks, §62, p40.
shims, §57, p34.
Exploding a blast, §54, p75.
External distance to a circular curve, §53, p35.
secant, §53, p35.
to a circular curve, §53, p35.
to a spiraled curve, §53, p35.

F

Facing a switch, Train, §58, p2.
Fall and rise, Influence of, on railroad location, §55, p5.
Excessive, in common roads, §60, p29.
Fastenings, Rail, §57, p13.
Fence, Railroad, Material for 1 mile of, §59, p30.
Fences, Railroad, §59, p27.
Railroad, Bracing of, §59, p29.
Railroad snow, §59, p30.
Field books for city work, §63, p55.
notes from railroad paper location, §55, p47.
work for transition spiral, §53, p26.
work in railroad location, §55, p54.
work of railroad preliminary survey, §55, p20.
work, Trestle, §56, p38.
Filing of city maps, §63, p54.
Fill, §54, p1.
Curvature correction for, in side-hill earthwork, §54, p54.
Transition from, to cut, §54, p38.
Filling, Joint, in granite-block pavements, §62, p34.
the joints of brick pavements, §62, p55.
the joints of wooden pavements, §62, p40.
Fills, Slope ratio in, §54, p3.
Final grade lines in railroad location, §55, p51.
location of a common road, §60 p36.
location of a railroad, §55, pp57, 59.
Fire protection of trestles, §56, p38.
protection of trestles against, Specifications for, §56, p49.
Flange of rail, §57, p8.
Floor of a trestle, §65, p10.
system for trestles, §56, p20.
Flux for asphalt, §62, p25.
Footwalks in trestles, §56, p38.
Footway, §64, p1.
Formula, Average-end-area, §54, p16.
Prismoidal, §54, p16.
Foundation, Cost of Telford, §61, p25.
for a rock-asphalt pavement, §62, p48.
for asphalt-block pavement, §62, p50.
for brick pavement, §62, p53.
for broken-stone road, §61, p16.
for granite-block pavement, §62, p31.
for sheet-asphalt pavement, §62, p42.
for wooden pavement, §62, p36.
of a pavement, §62, p2.
Specifications for Telford, §61, p31.
Foundations for framed bents, §56, p12.
Loose-rock, for framed bents, §56, p16.
Masonry, for framed bents, §56, p12.
Pile, for framed bents, §56, p13.
Fractions, Slope-stake, §54, p14.
Framed bents, §56, pp5, 12; §65, p10.
bents on solid rock, §56, p16.
trestle, §56, p2.
trestles, Cost of, §56, p4.
Framing of batter posts for framed bents, §56, p17.
of trestles, Specifications for, §56, p47.
Free haul in earthwork, Limit of, §54, p59.
Freight-yard tracks, Connection of, with main tracks, §59, p37.
yards, §59, p33.
yards, Loading appliances for, §59, p38
yards, Minor, §59, p37.
Friction, Axle, §60, p3.
of penetration, §60, pp4, 7.
Rolling, §60, p4.
Frictional resistance to traction, §60, p3.
Frog angle, §58, p16.
angles, Table of, §58, p17.
number, §58, p16.
number found by measurement, §58, p18.
numbers, Table of, §58, p17.
of a turnout, §58, p1.
Point of, §58, p12.
Frogs for turnouts, Description of, §58, p11.
Keyed, §58, p12.
Laying of, in tracks, §58, p60.
Plate, §58, p12.
Spring, §58. pp12, 14.
Stiff, §58, p12.
Furnace-slag roads, §61, p20.

G

Gaining in trestlework, §56, p6.
Gauge lines of rails, §65, p8.
 of track, §65, p8.
 Track, §57, p30.
 Widening of, in curves, §57, p38.
Gauging of track, §57, p30.
Grade, §54, p2.
 contour, §55, p21.
 line in final railroad location, §55, p58.
 lines, Final, in railroad location, §55, p51.
 Maintenance of, §57, p40.
 of a common road, §60, p9.
 of a road, Best, §60, p17.
 of a road, Maximum, §60, p16.
 of a road, Minimum, §60, p16.
 of a road, Ruling, §60, p16.
 profile for a railroad, §54, p6.
 resistance, §60, p8.
 stakes for streets and sewers, §63, p38.
 Total resistance on a, §60, p17.
 triangle, §54, p20.
Grades at street intersections, Adjustment of, §64, p31.
 Street, §64, p41.
Gradient, §54, p7.
Gradients, Adjustment of, in railroad location, §55, p45.
 for common roads, §60, p14.
Grading city surveys, §63, p37.
 of city lots, §63, p39.
 of highway ditches, §61, p3.
 of sewers, §63, p38.
Granite-block pavement, Drawing of, §65, p15.
 -block pavements, §62, p31.
 paving blocks, §62, p32.
Graphic determination of earthwork haulage, §54, p65.
Gravel ballast, §57, p2.
 drains, §61, p5.
 for sidewalks, §64, p22.
 roads, §61, p21.
 sidewalks, §64, p27.
Gravity, Resistance of, to traction in common roads, §60, p8.
Grillage for framed bents, §56, p14.
Ground lever for switch stands, §58, p10.
Growth of rock, §54, p56.
Guard-rail in trestlework, §56, p6.
 -rails for switches, §58, p19.
 -rails in curved track, §57, p39.
 -rails in straight track, §57, p39.
 -rails of a trestle, §65, p10.
 -rails of a turnout, §58, p1.
 -rails, Trestle, §56, p25.
 timbers of a trestle, §65, p10.
Guards, Cattle, for railroads, §59, p39.
 Covered-pit cattle, §59, p40.
 Open-pit cattle, §59, p40.
 Surface cattle, §59, p41.
Gutters, Concrete, §64, p15.
 for asphalt pavements, §62, p46.
 for city streets, §64, p10.

H

Hammer drilling, §54, p74.
Haul, Limit of free, in earthwork, §54, p59
Haulage, Average earthwork, §54, p69.
 of earthwork, §54, p59.
 of earthwork computed analytically §54, p60.
 of earthwork, Cost of, §54, p71.
 of earthwork determined graphically, §54, p65.
 of earthwork, Mass curve for, §54, p65.
 of earthwork, Mass diagram for, §54, p65.
 Total earthwork, §54, p69.
Head-block of a switch, §58, p2.
 of rail, §57, p8.
 -rod of a switch, §58, p3.
 -rods for switches, Common forms of, §58, p9.
Height of crown §64, p3.
High trestles, §56, p40.
Highways, Office of, §60, p1.
Hill, Measuring up or down, §63, p7.
Holes, Drip, §56, p17.
Horses, Tractive power of, §60, p12.
Houses, Engine, §59, p8.
 Section dwelling, §59, p5.
 Section tool, §59, p3.
Hubs, §60, p36.
Hydraulic base for sheet-asphalt pavement, §62, p42.

I

Inclined distances, Measuring of, §63 p7.
Index, Card, of city surveys, §63, p56.
Ineffective rise, §60, p29.
Inspection of ties, §57, p6.
Instruments used in city surveying, §63 p1.
 used in railroad preliminary surveys, §55, p19.
 used in railroad reconnaissance §55, p8.
Intersection of paved streets, Drawing of, §65, p14.
Iron for wooden trestles, Specifications for, §56, p48.
Irregular sections in earthwork, §54, p27.

J

Jack-stringers, in trestlework, §56, p6.
Jacks, Smoke, §59, p10.
Jaw breaker, §61, p14.

Jim crow, §57, p30.
Joint, Angle-splice, §57, p13.
  Pipe, Drawing of, §65, p22.
  Rail, Continuous, §57, p15.
  Rail, Weber, §57, p15.
  Supported, §57, p31.
  Suspended, §57, p31.
Joints of brick pavements, Filling of, §62, p55.
  of wooden pavements, Filling of, §62, p40.
  Rail, §57, p13.
  Rail, Location of, §57, p31.
  Trestle, Preservation of, §56, p40.

K

Key lots, §63, p33.
Keyed frogs, §58, p12.
Kink rails, §57, p30.

L

Labor in trestlework, Specifications for, §56, p50.
Ladder tracks, §58, p54.
  tracks for freight yards, §59, p36.
Lagscrews, §56, p33.
Lake asphalt, §62, p22.
Land asphalt, §62, p22.
Lateral bracing for trestles, §56, p29.
Lawn, §64, p1.
Lawns, §64, p19.
Laying asphalt for pavements, §62, pp45, 49.
  asphalt paving blocks, §62, p51.
  of ballast, §57, p24.
  of frogs in tracks, §58, p60.
  of rails, §57, p28.
  of ties, §57, p24.
  out of building lots, §63 p30.
  out of point switches, §58, p58.
  out of railroad fences, §59, p28.
  out of streets, §63, p26.
  out of stub switches, §58, p56.
  out of transition spirals, §53, p26.
  out of turnouts, §58, p55.
  paving bricks, §62, p54.
  Track, §57, p24.
Lead of a switch, §58, p20.
Length of a vertical curve, §55, p67.
  of rails, §57, p12.
  of rails in curved track, §57, p34.
  of spiral, Best, §53, p37.
  of spiral, Formula for, §53, p36.
  of spiral, Minimum, §53, p38.
  of switch rails for stub switch, §58, p22.
  Resisting, of a common road, §60, p29.
Level cuttings, Earthwork, §55, p38.
  party in railroad-location survey, §55, p55.
  party in railroad preliminary survey, §55, p28.
Level—(Continued)
  rod used in railroad surveying, §55, p29.
  -section equation §54, p10.
  Striding, §63, p10.
  Track, §57, p38.
Leveling in railroad-location survey, §55, p55.
  in railroad preliminary survey, §55, p28.
  of track, §57, p38.
Levels for city grades, §63, p37.
  in common-road location, §60, p37.
Lever, Ground, for switch stands, §58, p10
Life of pavements, §62, p6.
Limestone, Bituminous, §62, p24.
Limit of free haul in earthwork, §54 p59.
Limitations, Statute of, §63, p20.
Line, Building, §63, p17.
  Main, in railroad preliminary survey, §55, p34.
  monuments in cities, §63, p46.
  Property, §63, p17.
  rods used in city surveying, §63, p11.
Linear measurements in city surveying, §63, p2.
Lines, Branch, in railroad preliminary survey, §55, p34.
  Dotted, Use of, in drawings, §65, p13.
  Gauge, of rails, §65, p8.
  Spur, in railroad preliminary survey, §55, p34.
  Street, §63, p17.
Lining of track, §57, p42.
Loading appliances for freight yards, §59, p38.
  earthwork material, §54, p71.
Locating of bents in trestlework, §56, p38.
  party in railroad location, §55, p54.
Location, Example of railroad paper, §55, p45.
  Final, of a common road, §60, p36.
  Final railroad, §55, p57.
  of a common road, Example of, §60, p31.
  of a railroad, Final, Map of, §55, p59.
  of common roads, §60, pp21, 31.
  of turnouts, §58, p55.
  Paper railroad, §55, p43.
  profile, Railroad, §55, p58.
  Railroad, Adjustment of gradients in, §55, p45.
  Railroad, Economics of, §55, p1.
  Railroad, Engineering conditions affecting, §55, p4.
  Railroad, Field work, §55, p54.
  Railroad, Final grade lines in, §55, p51.
  Railroad, Influence of curvature on, §55, p6.
  Railroad, Influence of distance on, §55, p5.
  Railroad, Influence of maintenance expenses on, §55, p6.

Location — (Continued)
Railroad, Influence of rise and fall on, §55, p5.
Railroad, Influence of terminals on, §55, p6.
Railroad, Influence of towns on, §55, p6.
Railroad, Influence of traffic on, §55, p4.
Railroad, Method of, §55, p42.
Railroad, Preliminary survey for, §55, p18.
Railroad, Selection of route in, §55, p2.
Railroad, Theory of, §55, p1.
survey, Railroad, §55, p54.
Locks, Nut-, for rails, §57, p18.
Longitudinal brace in trestlework, §56, p6.
bracing for trestles, §56, p29.
Loop, Surface, for developing a railroad line, §55, p15.
Loosening of material in earthwork, §54, p71.
Lorenz switch, §58, p7.
Lot-and-block method of describing city blocks, §63, p17.
surveys, §63, p17.
surveys, Certificates and plots of, §63, p23.
Lots, Building, Laying out of, §63, p30.
City, Description of, §63, p17.
City, Grading of, §63, p39.
City, Relocation of, §63, p21.
Key, §63, p33.

M

Macadam pavements, §62, p35.
road, Drawing of, §65, p17.
roads, §61, p11.
roads, Specifications for, §61, p32.
Main line in railroad preliminary survey, §55, p34.
Maintenance, Cost of, as affecting railroad location, §55, p6.
of common roads, §61, p22.
of pavements, Cost of, §62, p10.
of track, §57, p40.
Maltha, §62, p25.
Map of final location of a railroad, §55, p59.
of subdivisional city survey, §63, p36.
Maps, City, Filing of, §63, p54.
Common-road, §60, p38.
Record city, §63, p53.
Right-of-way, §55, p60.
Use of, in railroad reconnaissance, §55, p7.
Marking pins for city surveying, §63, p2.
Masonry for common roads, Cost of, §61, p25.
for common roads, Specifications for, §61, p30.
foundations for framed bents, §56, p12.
Mass curve for earthwork haulage, §54, p65.
diagram for earthwork haulage, §54, p65.
Material for 1 mile of railroad fence, §59, p30.
Materials for city monuments, §63, p46.
for curbing, §64, p12.
Paving, §62, p19.
Paving, Absorptive capacity of, §62, p20.
Paving, Crushing strength of, §62, p20.
Paving, Resistance of, to abrasion, §62, p20.
Paving, Toughness of, §62, p20.
Tests of paving, §62, p19.
used for ballast, §57, p1.
Mean value, §63, p12.
Measure of precision, §63, p15.
Measurement, Repetition method of, §63, p11.
Measurements, Angular, in city surveying §63, p8.
angular, Precision in, §63, p16.
Linear, in city surveying, §63, p2.
Weighted, §63, p14.
Measuring on sloping ground, §63, p7.
Medicine kit for preliminary survey party, §55, p20.
Metes-and-bounds method of describing city blocks, §63, p19.
Middle ordinate of a curved rail, §57, p35.
ordinates for curving of rails, Table of, §57, p36.
Minimum grade of a road, §60, p16.
length of spiral, §53, p38.
Miter drains, §61, p7.
Monument records, §63, p56.
Monuments, City, §63, p45.
City, Materials for, §63, p46.
City, Witnessing of, §63, p47.
Line, in cities, §63, p46.
Witness, in cities, §63, p48.
Mortise in trestlework, §56, p6.
Most probable value, §63, p12.
Mountain route, §55, p15.
Mud ballast, §57, p3.
sill in trestlework, §56, p6.
-sills for framed bents §56, p13.

N

Natural asphalt, §62, p48.
-asphalt pavements, Construction of, §62, p48.
Nitroglycerin, Use of, in blasting, §54, p73.
Notching in trestlework, §56, p6.
Notebooks for city work, §63, p55.
Notes, Field, from railroad paper location, §55, p47.
for cross-sectioning, §54, p14.
for irregular sections in earthwork, §54, p30.
for three-level sections in earthwork, §54, p22.
Reconnaissance, §55, p9.

Notes—(Continued)
  Transit, for railroad preliminary survey, §55, p23.
Number, Frog, §58, p16.
Nut-locks for rails, §57, p18.

O

Obstacles, Passing, in railroad preliminary survey, §55, p32.
Office records, City, §63, p52.
  work in railroad preliminary survey, §55, p33.
Offset, Spiral, §53, p19.
  Spiral, Middle point of, §53, p21.
Offsets from preliminary railroad line, §55, p32.
Oil, Residuum, §62, p25.
Old track, Problems on the spiraling of, §53, p39.
  track, Spiraling of, §53, p33.
Open-pit cattle guards, §59, p40.
Ordinate, Middle, of a curved rail, §57, p35.
Ordinates, Quarter, for curved rails, §5.', p36.
Osculating circle of any curve, §53, p4.
Outer rail, Superelevation of, §53, p1.
  rail, Superelevation of, along a spiral curve, §53, p10.
Overhaul, Allowance for, §54, p70.

P

Packing-bolts in trestlework, §56, p6.
  -block in trestlework, §56, p6.
  blocks for trestles, §56, p22.
Paper railroad location, §55, p43.
Party, Chief of, in railroad preliminary survey, §55, p21.
  Level, in railroad preliminary survey, §55, p28.
  Locating, in railroad location, §55, p54.
  Preliminary survey, §55, p18.
  Topography, in railroad preliminary survey, §55, p31.
Passenger stations, §59, p1.
Pavement, Asphalt, adjoining railway track, §62, p47.
  asphalt, Drawing of, §65, p16.
  Bitulithic, §62, p27.
  granite-block, Drawing of, §65, p15.
  Principal parts of a, §62, p2.
Pavements, Adaptability of, §62, p4.
  Annual cost of, §62, p8.
  Asphalt-block, Construction of, §62, p50.
  Asphalt, Construction of, §62, p42.
  Belgian-block, §62, p31.
  Bitulithic, Construction of, §62, p52.
  Brick, Construction of, §62, p52.
  Broken-stone, §62, p35.
Pavements—(Continued)
  Choice of, §62, p3.
  Classification of, §62, p2.
  Cobblestone, §62, p30.
  Concrete for, §62, p28.
  Construction of, §62, p30.
  Construction of wooden, §62, p36.
  Cost of, §62, p7.
  Durability of, §62, p5.
  Economics of, §62, p8.
  Factors involved in the comparison of, §62, p3.
  Final value of, §62, p10.
  First cost of, §62, p9.
  Granite-block, §62, p31.
  Life of, §62, p6.
  Macadam, §62, p35.
  Object of, §62, p1.
  Prevention of slipperiness in, §62, p5.
  Requisites of good, §62, p1.
  Rock-asphalt, Construction of, §62 p48.
  Safety of, §62, p5.
  Sand for, §62, p28.
  Sandstone-block, §62, p34.
  Sheet-asphalt, §62, p42.
  Stone, Construction of, §62, p30.
  Stone for, §62, p21.
  Wear and tear of, §62, p4.
  Wood for, §62, p21.
Paving blocks, Asphalt, §62, p50.
  blocks, Wooden, §62, p37.
  blocks, Wooden, Chemical treatment of, §62, p41.
  brick, §62, p27.
  bricks, Dimensions of, §62, p53.
  bricks, Laying of, §62, p54.
  materials, Absorptive capacity of, §62, p20.
  materials, Comparative safety of, §62, p5.
  materials, Crushing strength of, §62, p20.
  materials, General description of, §62, p21.
  materials, Principal properties of, §62, p19.
  materials, Resistance of, to abrasion, §62, p20.
  materials, Selection of, §62, p18.
  materials, Tests of, §62, p19.
  materials, Toughness of, §62, p20.
  pitch, §62, p26.
Penetration, Friction of, §60, pp4, 7.
Petrolene, §62, p23.
Piers in preliminary railroad estimates, §55, p40.
Pile bent, §56, p5.
  bents, §56, p7.
  foundations for framed bents, §56, p13.
  trestle, §56, p2.
  trestles, Cost of, §56, p4.
Piles, Battered, §56, p6.

Piles—(Continued)
Braced, §56, p6.
Capping of, for pile bents, §56, p9.
Cutting off, for pile bents, §56, p9.
for bents, §56, p8.
for trestlework, Specifications for, §56, p46.
Timber suitable for, §56, p8.
Pins, Marking, for city surveying, §63, p2.
Pipe culverts for common roads, Specifications for, §61, p30.
drain, Cost of, §61, p25.
Pitch, Paving, §62, p26.
Pits, Borrow, §54, p42.
Places (intermediate streets), §63, p29.
Plate frogs, §58, p12.
title: Dams and pipes, §65, p18.
title: Railroad construction, §65, p2.
title: Streets and pavements, §65, p14.
Plates, Directions for drawing, §65, p2.
Drawing, General description of, §65, p1.
Tie-, for rails, §57, p15.
Platform stations, §59, p1.
Plot of city-lot survey, §63, p23.
Point of curve of a spiraled curve, §53, p19.
of frog, Actual, §58, p12.
of frog, Theoretical, §58, p12.
of spiral, §53, p8.
of spiral, Second, §53, p8.
of switch, §58, p4.
of tangent in a spiraled curve, §53, p22.
switch, §58, p3.
switches, §58, p6.
switches, Dimensions for, §58, p25.
switches, Laying out of, §58, p58.
Points, Controlling, in railroad location, §55, p3.
Corresponding, §53, p29.
Pole tie, §57, p5.
Possession, Adverse, §63, p20.
Posts, Battered, in trestlework, §56, p6.
in framed bents, §56, p17.
Powder, Detonating, §54, p74.
Slow-burning, §54, p73.
Power of horses, Tractive §60, p12.
Prairie route, §55, p10.
Precision and accuracy Difference between, §63, p16.
in angular measurements, §63, p16.
Measure of, §63, p15.
of surveying measurements, §63, p12.
required in city surveying, §63, p16.
Preliminary estimate for a railroad, §55, p36.
railroad estimate, Form of, §55, p41.
survey for a railroad, §55, p18.
survey for common roads, §60, p23.
survey of railroad, Field work of, §55, p20.
survey Railroad, Equipment for, §55, p19.
Preservation of trestle joints, §56, p40.
Prism, Right section of, §63, p40.
Prismoid, Triangular, §54, p17.
Prismoidal correction, §54, p17.
correction for three-level-section prismoid §54, p20.
correction for triangular prismoid, §54, p17
Prismoidal formula, §54, p16.
Prismoids, Earthwork, §54, p16.
Private city surveys, §63, p55.
Probable error, §63, p13.
value, Most, §63, p12.
Problems on tangent distances in spiraled curves, §53, p22.
on the selection of spirals, §53, p39.
on the spiraling of old track, §53, p39.
Profile, Construction, for a common road, §60 p37.
Grade, for a railroad, §54, p6.
Location, §55, p58.
Profiles for city grades, §63, p37.
in railroad location, §55, p57.
Property line, §63, p17.
Proposals for common-road construction, §61, p24.
Protection of common-road side slopes, §60 p44.
of trestles against fire, Specifications for, §56, p49.
Protractor, Curved, §55, p43.
Pull, Correction of tape for, §63, p4.
Necessary, to neutralize sag of tape, §63, p6.

Q

Quantities estimated in common-road specifications, §61, p29.
Quarter ordinates for curved rails, §57, p36
ties, §57, p6.

R

Radius of curvature of any curve, §53, p4.
of turnout for stub switch, §58, p19.
Rail, Base of, §57, p8.
bender, §57, p30.
braces, §57, p16.
fastenings, §57, p13.
Flange of, §57, p8.
Head of, §57, p8.
joint, Continuous, §57, p15.
joint, Weber, §57, p15.
joints, §57, p13.
joints, Location of, §57, p31.
Required weight of, §57, p10.
Spring, §58, p14.
Superelevation of outer, §53, p1.
Switch, §58, p1.
Web of, §57, p8.

Railroad coaling stations, §59, p19.
construction, Preliminary estimate, §55, p36.
fences, §59, p27.
location, Adjustment of gradients in, §55, p45.
location, Controlling points in, §55, p3.
location, Curvature in, §55, p48.
location, Economics of, §55, p1.
location, Engineering conditions affecting, §55, p4.
location, Example of paper, §55, p45.
location, Final, §55, p57.
location, Final grade lines in, §55, p51.
location, Influence of curvature on, §55, p6.
location, Influence of distance on, §55, p5.
location, Influence of maintenance expenses on, §55, p6.
location, Influence of rise and fall on, §55, p5.
location, Influence of terminals on, §55, p6
location, Influence of towns on, §55, p6.
location, Influence of traffic on, §55, p4.
location, Preliminary survey for, §55, p18.
location, Selection of route in, §55, p2.
location survey, §55, p54.
location, Theory of, §55, p1.
Preliminary estimate for, §55, p36.
roadbed, §65, p7.
roadbed, Drawing cross-section of, §65, p7.
section buildings, §59, p3.
sections, §55, p56.
snow fences, §59, p30.
snow sheds, §59, p32.
stations, §59, p1.
subgrade, §65, p7.
water stations, §59, p11.
water tanks, §59, p11.
Rails, §57, p7.
Chemical composition of, §57, p12.
Cost of, §57, p20.
Curving of, §57, p35.
Drawing of, §65, p8.
Expansion of, §57, p33.
Guard-, for switches, §58, p19.
Guard-, in curved track, §57, p39.
Guard-, in straight track, §57, p39.
Guard-, of a turnout, §58, p1.
Handling of, §57, p28.
Kink, §57, p30.
Laying of, §57, p28.
Length of, §57, p12.
Length of, in curved track, §57, p34.
per mile of track, §57, p22.
Spiking of, §57, p32.
Standard form of, §57, p8.
Standard T, Drawing of, §65, p2.
Straightening of, §57, p30.
Rails—(Continued)
Testing of, §57, p12.
Unloading of, §57, p28.
Weight of, per mile of track, §57, p21.
Weights and dimensions of standard, §57, p9.
Wing, of a turnout frog, §58, p12.
Ramming of brick pavements, §62, p54.
of granite-block pavements, §62, p33.
of wooden pavement, §62, p39.
Rate of slope, §54, p2.
Rattler used in abrasion tests, §62, p21.
Raveling of broken-stone roads, §61, p23.
Receiving tracks, §59, p35.
Reconnaissance for common roads, §60, p21.
for railroad location, §55, p7.
notes, §55, p9.
Record city maps, §63, p53.
of cost of city surveys, §63, p57.
Records, City office, §63, p52.
Monument, §63, p56.
of street grades, §64, p43.
Reference stakes for common roads, §60, p36.
Refuge bays in trestles, §56, p37.
Relocation of city lots, §63, p21.
Repairs, Number of ties needed for, §57, p44.
Repetition method of measurement, §63, p11.
Report on proposed common road, §60, p37.
Repose, Angle of, §60, p14.
Residuum oil, §62, p25.
Resistance, Air, in common roads, §60, p3.
Grade, §60, p8.
on a grade, Total, §60, p17.
of gravity to traction in common roads, §60, p8.
to rolling, §60, p3.
to traction due to collision, §60, p10.
to traction on common roads, §60, p3.
Resisting length of a common road, §60, p29.
Retine, §62, p23.
Ribbons of a trestle, §65, p10.
Riding the frog, Wheels, §58, p12.
Right of way, §55, p60.
of way, Clearing of, §54, p5.
-of-way maps, §55, p60.
of way of common roads, §60, p20.
section of a prism, §63, p40.
Rise and fall, Influence of, on railroad location, §55, p5.
Ineffective, §60, p29.
Risks, Contractor's, in trestle construction, §56, p49.
Road, Common, Example of location of, §60, p31.
construction, Cost of, §61, p24.
Macadam, Drawing of, §65, p17.
maps, Common-, §60, p38.

Roadbed, §54, p2.
for railroads, §57, p26.
of broken-stone road, §61, p16.
Roadbeds, Railroad, §65, p7.
Railroad, Drawing cross-section of, §65, p7.
Roads, Advantages of good, §60, p2.
Broken-stone, §61, p11.
Charcoal, §61, p20.
Chert, §61, p20.
Common, §60, p1.
Common, Earthwork for, §60, p41.
Common, Selection of route for, §60, p24.
Construction of, §61, p9.
Contract for construction of, §61, p26.
Corduroy, §61, p20.
Cross-section of common, §60, p18.
Furnace-slag, §61, p20.
Gravel, §61, p21.
in clay soils, §61, p10.
in sandy soils, §61, p10.
Location of common, §60, p21.
Macadam, §61, p11.
Maintenance of, §61, p22.
Natural, §61, p9.
Proposals for the construction of, §61, p24.
Requisites for good, §60, p1.
Sawdust, §61, p19.
Shell, §61, p20.
Tan-bark, §61, p19.
Telford, §61, p11.
Width of common, §60, p20.
Roadway, Street, Coordinates for cross-section of, §64, p7.
Street, Width of, §64, p1.
Rock asphalt, §62, pp24, 48.
Bituminous, §62, p48.
breakers, §61, p14.
crushers, §61, p14.
excavation for common roads, Cost of, §61, p24.
excavation in common roads, Specifications for, §61, p30.
Framed bents on, §56, p16.
Growth of, §54, p56.
in compound-section earthwork, §54, p39.
Loose, Foundations of, §56, p16.
Rod, Connection-, of a switch, §58, p3.
Head-, of a switch, §58, p3.
Level, used in railroad surveying, §55, p29.
Rodman in railroad preliminary survey, §55, p30.
Rods, Head-, for switches, Common forms of, §58, p9.
Line, used in city surveying, §63, p11.
Tie-, for switches, §58, pp3, 9.
Rolling friction, §60, p4.
of roads, Specifications for, §61, p33.
Rolling—(Continued)
Resistance to, §60, p3.
Rotary crushers, §61, p14.
Roundhouses, §59, p8.
Route, Cross-country, §55, p13.
Mountain, §55 p15.
Prairie, §55, p10.
Selection of, for a common road, §60, pp24, 31.
Selection of, in railroad location, §55, p2.
Valley, §55, p12.
Routes, Classification of railroad, §55, p10.
for common roads, Comparison of, §60, p27.
Relative economy of, in railroad location, §55, p2.
Rubble masonry for common roads, Specifications for, §61, p30.
Ruling grade of a road, §60, p16.

S

Safety of pavements, §62, p5.
switch, §58, p7.
Sag between grade lines, §55, p61.
Correction of tape for, §63, p5.
of tape, Necessary pull to neutralize, §63, p6.
Vertical curve at a, §55, p63.
Sags in track, Removal of, §57, p41.
Sand for paving, §62, p28.
Sandstone, Bituminous, §62, p24.
-block pavements, §62, p34.
Sandy soils, Roads in, §61, p10.
Sawdust roads, §61, p19.
Scales, Track, §59, p39.
Screens for broken stone, §61, p15.
Seasoning of ties, §57, p4.
Secant, External, §53, p35.
Second point of spiral, §53, p8.
Section buildings, Railroad, §59, p3.
dwelling houses, §59, p5.
Right, of a prism, §63, p40.
tool houses, §59, p3.
Sections, compound, Volume of earthwork between, §54, p39.
Earthwork compound, §54, p13.
Earthwork three-level, §54, p20.
Irregular, in earthwork, §54, p27.
Railroad, §55, p56.
Selection of paving materials, §62, p18.
of route for a common road, §60, p24.
of route in railroad location, §55, p2.
of spirals, §53, p37.
of spirals, Problems on, §53, p39.
Separators for trestles, §56, p22.
Service cost of pavements, §62, p12.
Sewers, Grading of, §63, p38.
Trench stakes for, §63, p38.

Shanty, Watchman's, §59, p8.
Sheds, Snow, for railroads, §59, p32.
Sheet-asphalt pavements, §62, p42.
-asphalt sidewalks, §64, p26.
Shell ballast, §57, p3.
roads, §61, p20.
Shelter sheds, §59, p1.
Shelves in compound-section earthwork, §54, p40.
Shimming track, §57, p40.
Shims, §57, p40.
Expansion, §57, p34.
Shoulder stones, §61, p16.
Shrinkage of earthwork, §54, p55.
Side ditches for highways, §61, p8.
-hill earthwork, §54, p34.
-hill earthwork, Area of end sections in, §54, p34.
-hill earthwork, Curvature correction in, §54, p51.
slope of a cut or fill, §54, p2.
slopes for common roads, §60, p41.
Sidewalk, §64, p1.
Sidewalks, Artificial-stone, §64, pp21, 23.
Asphalt-tile, §64, p27.
Brick, §64, p24.
Gravel, §64, p27.
Heights of, §64, p17.
Lateral slopes of, §64, p18.
Materials for, §64, pp17, 21.
Natural-stone, §64, pp21, 22.
Sheet-asphalt, §64, p26.
Widths of, §64, p17.
Wooden, §64, p27.
Sighting board, §57, p41.
Signals, Switch, §58, p7.
used in surveying, §55, p27.
Sill in trestlework, §56, p6.
of a trestle, §65, p13.
Size of city blocks, §63, p28.
Slab ties, §57, p6.
Slag ballast, §57, p2.
roads, §61, p20.
Slope, Rate of, §54, p2.
ratio in cuts, §54, p3.
ratio in fills, §54, p3.
Side, of a cut or fill, §54, p2.
-stake equations, §54, p10.
-stake fractions, §54, p14.
stakes, §54, p9.
stakes, Setting of, §54, p15.
Slopes, Lateral, of sidewalks, §64, p18.
Protection of common-road, §60, p44.
Side, for common roads, §60, p41.
Sloping crown, §64, pp6, 8.
ground, Measuring on, §63, p7.
Slow-burning powder, §54, p73.
Smoke jacks, §59, p10.
Snow fences for railroads, §59, p30.
sheds for railroads, §59, p32.
Soils, Clay, Roads in, §61, p10.
Sandy, Roads in, §61, p10.
Spacing of ties, §57, p26.
Specifications for the rolling of roads, §61, p33.
for wooden trestles, §56, p46.
for broken-stone roads, §61, p23.
for macadam roads, §61, p32.
for ties, §57, p6.
Speed of greatest work for a horse, §60, p13.
Spike-killed ties, §57, p5.
Spikes, Bolt, §56, p32.
for rails, §57, p17.
Cut, §56, p32.
for rails, Cost of, §57, p24.
for rails, Dimensions of, §57, p23.
per mile of track, §57, p23.
used in trestles, §56, p32.
Spiking of rails, §57, p32.
Spiral, Best length of, §53, p37.
bridge for developing a railroad line, §55, p16.
Coordinates of, §53, p18.
Degree of curve at any point of, §53, p9.
Formula for length of, §53, p36.
Methods for laying out, §53, p26.
Minimum length of, §53, p38.
offset, §53, p19.
offset, Middle point of, §53, p21.
Point of, §53, p8.
Second point of, §53, p8.
Superelevation of outer rail in, §53, p10.
t correction for, §53, p20.
Transition, Advantages of, §53, p12.
Transition, defined, §53, p7.
Transition, General properties of, §53, p9.
Tunnel, for developing a railroad line, §55, p17.
Unit degree of curve of, §53, p9.
x correction for, §53, p19.
Spirals, Insertion of, in old track, §53, p33.
Selection of, §53, p37.
transition, Tables of, §53, p46.
transition, Tables of, explained, §53, p15.
Split caps for piles, §56, p11.
Spoil banks, §60, p41.
Spreaders between trestle stringers, §56, p21.
Spreading carts, §61, p17.
of earthwork, §54, p72.
Spring frogs, §58, p12.
frogs, Forms of, §58, p14.
rail, §58, p14.
Sprinkling and cleaning of pavements, Cost, of, §62, p11.

Spur between grade lines, §55, p61.
lines in railroad preliminary survey, §55, p34.
Vertical curve at a, §55, p62.
Stake, Depth of a, §54, p7.
Stakeman in railroad preliminary survey, §55, p25.
Stakes, Grade, for streets and sewers, §63, p38.
in railroad-location survey, §55, p55.
in track laying, §57, p25.
Reference, for common roads, §60, p36.
Slope, §54, p9.
used in railroad preliminary survey, §55, p28.
Staking out common-road work, §60, p40.
Standard form of rails, §57, p8.
length of tape, §63, p3.
plans for trestles, §56, p40.
railroad water tanks, §59, p13.
rails, Weights and dimensions of, §57 p9.
tie, §57, p6.
Station as a unit, §53, p8.
Equality, §55, p36.
Stations, Passenger, §59, p1.
Railroad, §59, p1.
Railroad coaling, §59, p19.
Railroad water, §59, p11.
Statute of limitations, §63, p20.
Steel tape used in city surveying, §63, p2.
Stiff frogs, §58, p12.
Stone, Breaking of, for common roads, §61, p14.
Broken-, ballast, §57, p1.
Broken, for common roads, §61, p13
curbing, §64, p13.
for common roads, §61, p25.
for pavements, §62, p21.
pavements, Construction of, §62, p30.
Stones, Border, §61, p16.
Bridge, for city streets, §64, p28.
Crossing, for city streets, §64, p28.
Edge, §61, p16.
Shoulder, §61, p16.
Straightening of rails, §57, p30.
Street grades, §64, p41.
grades, Records of, §64, p43.
intersection, Drawing of, §65, p14.
intersections, §64, p29.
intersections, Crown at §64, p36.
intersections, Drainage at, §64, p39.
lines, §63, p17.
Parts of a, §64, p1.
roadway, §64, p1.
roadway, Cross-section of, §64, p2.
roadway, Width of, §64, p1.
Streets, Grade stakes for, §63, p38.
Grading of, §63, p37.
Laying out of, §63, p26.
of the city of Washington, §63, pp27, 29.
Widths of, §63, p28.
Strength, Crushing, of paving materials, §62 p20.
Striding level, §63, p10.
Stringers for trestles, §56, pp7, 21; §65, p10.
for trestles, Size of, §56, p23.
Strip, Waling, in trestlework, §56, p7.
Stub switch, §58, pp3, 4.
switches, Dimensions of, §58, p23.
switches, Formulas for, §58, p19.
switches, Laying out of, §58, p56.
Subdivision of a large city tract, §63, p33.
of a small city tract, §63, p31.
Subdivisional city surveys, §63, p26.
Subgrade, §54, p1.
of a broken-stone road, §61, p16.
of a railroad, §57, p1; §65, p7.
Preparation of, for ballast, §57, p24.
Sub-sills for framed bents, §56, p13.
Subsoil drainage, §61, p1.
drains, Arrangement of, §61, p6.
Superelevating the outer rail, §57, p38.
Superelevation of outer rail, §53, p1.
of outer rail along a spiral curve, §53, p10.
of outer rail in unspiraled curves, §53, p3.
Supported joint, §57, p31.
Surface cattle guards, §59, p41.
coat for asphalt pavement, §62, p45.
drainage, §61, p1.
loop for developing a railroad line, §55, p15.
Wearing, of a pavement, §62, p2.
Survey, Location, for railroad, §55, p54.
Preliminary, for a railroad, §55, p18.
Surveying, City, §63, p1.
Surveyors, City, Duties of, concerning encroachments, §63, p20.
Surveys, City, Grading, §63, p37.
City, Private, §63, p55.
City, Subdivisional, §63, p26.
Earthwork, §54, p1.
for building lots, §63, p30.
for city lot grading, §63, p39.
Lot, §63, p17.
Preliminary, for common roads, §60, p23.
Suspended joint, §57, p31.
Sway-brace in trestlework, §56, p6.
-braces of a trestle, §65, p13.
-bracing for trestles, §56, p28.
Switch, §58, p1.
Lorenz, §58, p7.
Point, §58, p3.
Point of, §58, p4.

Switch—(Continued)
rail, §58, p1.
rails for stub switch, Length of, §58, p22.
Safety, §58, p7.
signals, §58, p7,
stands, §58, p10.
Stub, §58, p3.
targets, §58, pp7, 10.
Throw of, §58, p1.
Throwing the, §58, p3.
ties, §58, p60.
ties, Tamping of, §58, p61.
timbers, §58, p60.
Train facing, §58, p2.
Train trailing, §58, p2.
Switchbacks for developing a railroad line, §55, p17.
Switches, §58, p3.
Kinds of, §58, p3.
Point, §58, p6.
Point, Dimensions for, §58, p25.
Point, Laying out of, §58, p58.
Stub, §58, p4.
Stub, Dimensions of, §58, p23.
Stub, Formulas for, §58, p19.
Stub, Laying out of, §58, p56.
Stub, Length of switch rails for, §58, p22.
Switching engines, Cost of, §59, p33.
Symmetrical crown, §64, p7.

T

Table for vertical curves, §55, p65.
of coefficients for roadway crowns, §64, p4.
of coefficients of rolling friction for common roads, §60, p5.
of consequent damages in pavements, §62, p13.
of cost of cleaning and sprinkling of pavements, §62, p11.
of cost of embankments and trestles, §56, p3.
of cost of maintenance of pavements, §62, p11.
of cost of pile and framed trestles, §56, p4.
of cost of wear and tear of pavements, §62, p4.
of dimensions of point switches, §58, p27.
of dimensions of stub-switch turnouts, §58, p23.
of final value of paving materials, §62, p10.
of first cost of pavements, §62, p9.
of frog numbers and angles, §58, p17.
of growth of rock, §54, p57.
of ingredients for concrete for pavements, §62, p29.
of ingredients for paving asphalt, §62, p44.
of level cuttings, §55 p39.

Table—(Continued)
of life of pavements, §62, p6.
of middle ordinates for curving of rails, §57, p36.
of minimum spiral lengths, §53, p38.
of rails, angle bars, and bolts, per mile of track, §57, p22.
of service cost of pavements, §62, p12.
of shrinkage of earthwork, §54, p56.
of spaces between ends of rails, §57, p33.
of spikes per mile of track, §57, p23.
of standard rails, §57, p9.
of superelevations of outer rail, §53, p45.
of ties per mile of track, §57, p20.
of track bolts in 200-pound keg, §57, p22.
of weight of rails per mile ot track, §57, p21.
Tables of transition spirals, Explanation ot, §53, p15.
of transition spirals, §53, p46.
Tamping in blasting, §54, p75.
of switch ties, §58, p61.
Tan-bark roads, §61, p19.
Tangent distances in spiraled curves, Problems on, §53, p22.
Point of, in a spiraled curve, §53, p22.
to any curve, §53, p5.
Tangents, Running of, in railroad-location survey, §55, p56.
Tanks, Railroad water, §59, p11.
Standard water, for railroads, §59, p13.
Track, §59, p18.
Tape, Corrections to length of, §63, p3.
Standard length of, §63, p3.
Steel, used in city surveying, §63, p2.
Tar, Coal, §62, p26.
concrete for sidewalks, §64, p22.
Targets, Switch, §58, pp7, 10.
t correction for a spiral, §53, p20.
Technical terms used in trestlework, §56, p4.
Telford foundation, Cost of, §61, p25.
foundation, Specifications for, §61, p31.
roads, §61, p11.
Temperature coefficient of steel tapes, §63, p3.
Correction of tape for, §63, p3.
Templet for framing batter posts, §56, p18
Tenon, §56, p7.
Terminals, Influence of, on railroad location, §55, p6.
Testing asphalt cement, §62, p25.
of rails, §57, p12.
Tests of paving materials, §62, p19.
of stone for common roads, §61, p13.
Three-level earthwork sections, §54, p20.
-level section prismoids, Notes for, §54, p22
Throat of a frog, §58, p12.

Throw of a switch, §58, p1.
Throwing the switch, §58, p3.
Tie-plates for rails, §57, p15.
Pole, §57, p5.
-rod for switches, Common forms of, §58, p9.
-rods of a switch, §58, p3.
Standard, §57, p6.
Ties, Chemical treatment of, §57, p7.
Cost of, §57, p20.
Distributing of, §57, p24.
Durability of, §57, p5.
Hewn, §57, p6.
Inspection of, §57, p6.
Kinds of, §57, p5.
Laying of, §57, p24.
Number of, needed for repairs, §57, p44.
Placing of new, in old track, §57, p44.
Quarter, §57, p6.
Railroad, §57, p3.
required per mile of track, §57, p20.
Sawed, §57, p6.
Seasoning of, §57, p4.
Slab, §57, p6.
Spacing of, §57, p26.
Specifications for, §57, p6.
Spike-killed, §57, p5.
Switch, §58, p60.
Trestle, §56, p24.
Woods used for, §57, p3.
Tile, Asphalt-, sidewalks, §64, p27.
drains, §61, p5.
Tiles, Asphalt, §62, p50.
Timber for trestlework, §56, p46.
for wooden trestles, Chemical treatment of, §56, p48.
Specifications for creosoted, §56, p48.
suitable for piles, §56, p8.
trestle, Drawing of, §65, p10.
Timbers, Guard, of a trestle, §65, p10.
Switch, §58, p60.
Tongue of a turnout frog, §58, p12.
Tonnage in streets and roads, §62, p15
Tool houses, Section, §59, p3.
Topography party in railroad preliminary survey, §55, p31.
in railroad-location survey, §55, p55.
Taking of, in railroad preliminary survey, §55, p31.
Toughness of paving brick, §62, p27.
of paving materials, §62, p20.
Towns, Influence of, on railroad location, §55, p6.
Track, Asphalt pavement adjoining, §62, p47.
bolts, §57, p18.
bolts, Cost of, §57, p21.
bolts in 200-pound keg, §57, p22.
bolts per mile of track, §57, p22.
Track—(Continued)
connecting curves, §58, p35.
construction, Preliminary work in, §54, p5.
Cost of, §57, p19.
crossing, §58, p62.
crossings, Formulas for, §58, p63.
Curved, §57, p34.
drainage, Ditching for, §54, p5.
gauge, §57, p30.
Gauge of, §65, p8.
Gauging of, §57, p30.
General care of, §57, p45.
Grade profile for, §54, p6.
laying, §57, p24.
level, §57, p38.
Leveling of, §57, p38.
Lining of, §57, p42.
Maintenance of, §57, p40.
Old, Problems on the spiraling of, §53, p39.
Old, Spiraling of, §53, p33.
Placing of new ties in, §57, p44.
Removal of sags in, §57, p41.
scales, §59, p39.
Shimming of, §57, p40.
tanks, §59, p18.
Tracks, Departing, for freight yards, §59, p37.
Ladder, §58, p54.
Ladder for freight yards, §59, p36.
parallel, Connection of, §58, p35.
parallel curved, Connection of, §58, p37.
parallel curved, Cross-over between, §58, p49.
parallel straight, Cross-over between, §58, p44.
Receiving, §59, p35.
Traction, Frictional resistance to, in common roads, §59, p3.
on common roads, §60, p3.
Tractive power of horses, §60, p12.
Traffic census, §62, p15.
Cost of, in streets and roads, §62, p17
Volume of, in railroad location, §55, p4.
Trailing a switch, Train, §58, p2.
T rails, Drawing of, §65, p2.
Standard, §65, p2.
Train-mile, §55, p5.
Transit, City, §63, p8.
notes for railroad preliminary survey, §55, p23.
Transit, Use of, in railroad preliminary survey, §55, p20.
Transition curve, §53, p3.
from cut to fill, §54, p38.
spiral, Advantages of, §53, p12.
spiral defined, §53, p7.
spiral, General properties of, §53, p9.
spirals, Insertion of, in old track, §53, p33.

Transition—(Continued)
spirals, Methods for laying out, §53, p26.
spirals, Tables of, §53, p46.
spirals, Tables of, explained, §53, p15.
Transitman in railroad-location survey, §55, p54.
in railroad preliminary survey, §55, p22.
Transportation on common roads, Cost of, §60, p2.
Treatment of ties, Chemical, §57, p7.
Treenail, §56, p7.
Trestle bent, §56, p2.
bents, §65, p10.
Connection of, with embankment, §56, p34.
construction, Details of, §56, p32.
design, §56, p45.
field work, §56, p38.
Framed, §56, p2.
guard-rails, §56, p25.
joints, Preservation of, §56, p40.
Parts of a, §65, pp10, 13.
Pile, §56, p2.
ties, §56, p24.
Timber, Drawing of, §65, p10.
Wooden, §56, p1.
Trestles, §56, p1.
and embankments, Comparative cost of, §56, p2.
Bracing for, §56, p28.
Classification of, §56, p2.
Cost of, §56, p4.
creosoted, Specifications for, §56, p48.
Erection of, §56, p39.
Floor system for, §56, p20.
High, §56, p40.
in preliminary railroad estimates, §55, p40.
on curves, §56, p30.
Protection of, against fire, §56, p38.
Specifications for wooden, §56, p46.
Standard plans for, §56, p40.
Trestling, Extent of, in the United States, §56, p1.
Technical terms used in, §56, p4.
Triangle, Adjustment of angles in, §63, p12.
Grade, §54, p20.
Triangular prismoid, §54, p17.
Tunnel spiral for developing a railroad line, §55, p17.
Turning points in railroad-location survey, §55, p55.
points used in railroad preliminary survey, §55, p31.
Turnout, §58, p1.
formulas for stub switches, §58, p19.
from outer side of curved track, §58, p28.
to inner side of curved track, §58, p33.
Turnouts, §58, p1.
Turnouts—(Continued)
for connecting curves, §58, p35.
for cross-overs, §58, p44.
Laying out of, §58, p55.
Location of, §58, p55.
Turntables, §59, p24.

U

Unit degree of spiral, §53, p9.

V

Valley route, §55, p12.
Value, Mean, §63, p12.
Most probable, §63, p12.
Vertical curve at a sag, §55, p63.
curve at a spur, §55, p62.
curve, Length of, §55, p67.
curves, §55, p61.
curves, Table for, §55, p65.
Vitrification of paving brick, §62, p27.
Volume of earthwork between compound sections, §54, p39.
of earthwork, Computations for, §54, p15.
of earthwork in lot grading, §63, p40.
of earthwork in side-hill work, §54, p36.
of irregular-section prismoid, §54, p27.
of three-level-section prismoid, §54, p20.
of triangular prismoid, §54, p17.
Volumes, Computation of, in street grading, §63, p43.
Earthwork, Accuracy in computing, §54, p58

W

Waling strip in trestlework, §56, p7.
Washers used in trestlework, §56, p34.
Washington city, Streets of, §63, pp27, 29.
Watchman's shanty, §59, p8.
Water brakes, §61, p9.
columns, §59, p16.
Methods of representing, §65, p20.
stations, Railroad, §59, p11.
supply for railroad water tanks, §59, p13.
tanks, Railroad, §59, p11.
tanks, Railroad standard, §59, p13.
Way, Right of, §55, p60.
Wearing surface of a pavement, §62, p2
Web of rail, §57, p8.
Weber rail joint, §57, p15.
Weighing of loaded cars, §59, p39.
Weighted measurements, §63, p14.
Weight of rail required, §57, p10.
of rails per mile of track, §57, p21.
Weights of standard rails, §57, p9.
Width of common roads, §60, p20.
of embankments, §54, p4.
of excavations, §54, p4.
of right of way for common roads, §60, p20
of street roadways §64, p1.
Widths of streets, §63, p28.

Wing rails of a turnout frog, §58, p12.
Witness monuments in cities, §63, p48.
Wood for pavements, §62, p21.
  for sidewalks, §64, p22.
Wooden pavements, Construction of, §62, p36.
  paving blocks, §62, p37.
  paving blocks, Chemical treatment of, §62, p41.
  paving blocks, Expansion of, §62, p40.
  sidewalks, §64, p27.
  trestle, §56, p1.
  trestles, Specifications for, §56, p46.
Woods used for ties, §57, p3.
Work, Extra, Specifications for, in trestling §56, p51.
  of a horse, §60, p12.
  Office, in railroad preliminary survey, §55, p33.

X

x correction for a spiral, §53, p19.

Y

Yards, Freight, §59, p33.
  Minor freight, §59, p37.

DATE OF ISSUE

This book must be returned within 3/7/14 days of its issue. A fine of ONE ANNA per day will be charged if the book is overdue.